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Bioventing Pilot Test Work Plan for Site B-2093 and Site D-10 Kelly AFB, Texas

D R A F T
Part II
Draft Interim Pilot Test Results Report for Site B-2093 and Site D-10 Kelly AFB, Texas

Prepared for

Air Force Center for Environmental Excellence
Brooks AFB, Texas

and

Kelly Air Force Base
San Antonio, Texas

April 1994

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1700 Broadway, Suite 900 • Denver, Colorado 80290 • (303) 831-8100 • Fax (303) 831-8208

April 1, 1994

Mr. Jerry Hansen
AFCEE/EST
8001 Arnold Drive
Brooks AFB, TX 78235-5357

Dear Mr. Hansen:

Attached please find three draft copies of the Kelly AFB draft bioventing pilot test results interim report for sites B2093 and D10. A copy has also been provided to Stephen Escude of Kelly AFB.

If you should have any questions regarding this report, or on the progress of the Kelly AFB continuing bioventing pilot test activities, please call Brian Vanderglas in the Engineering-Science Austin office at (512) 719-6000, or myself in the Denver office at (303) 831-8100.

Sincerely,

ENGINEERING-SCIENCE, INC.

Doug C. Downey

Douglas C. Downey
Project Manager

Attachments

xc: Brian Vanderglas, ES Austin

Part I
Bioventing Pilot Test Work Plan for Site B-2093 and Site D-10 Kelly AFB, Texas

Prepared for

Air Force Center for Environmental Excellence
Brooks AFB, Texas
and

Kelly Air Force Base
San Antonio, Texas

Prepared by

Engineering-Science, Inc.
Austin, Texas

April 1994

CONTENTS

Page

FIGURES

Page

BIOVENTING PILOT TEST WORK PLAN FOR SITES B-371, B-2093, AND D-10 KELLY AIR FORCE BASE, TEXAS

1.0 INTRODUCTION

This work plan presents the scope of multi-phased bioventing pilot tests for *in situ* treatment of fuel-contaminated soils at sites B-371, B-2093, and D-10 at Kelly Air Force Base (AFB), Texas. The locations of the three sites at Kelly AFB are presented in Figure 1.1. The pilot tests will be performed by Engineering-Science, Inc. (ES). The three primary objectives of the proposed pilot tests are: 1) to assess the potential for supplying oxygen throughout the contaminated soil interval, 2) to determine the rate at which indigenous microorganisms will degrade fuel when supplied with oxygen-rich soil gas, and 3) to evaluate the potential for sustaining these rates of biodegradation until fuel contamination is remediated to concentrations below regulatory standards.

The pilot tests will be conducted in two phases. A vent well (VW) and monitoring points (MPs) will be installed during site investigation activities. The initial test phase at each site will also include an *in situ* respiration test, an air permeability test, and installation of a blower system for air injection. This initial testing is expected to take approximately 2 weeks. During the second phase, the bioventing systems will be operated and monitored over a 1-year period.

If bioventing proves to be an effective means of remediating soil contamination at these sites, pilot test data may be used to design full-scale remediation systems and to estimate the time required for site cleanup. An added benefit of the pilot testing at these three sites is that a significant amount of the fuel contamination should be biodegraded during the 1-year pilot test, as the testing will take place within the most contaminated soils at the sites. Additional background information on the development and recent success of the bioventing technology is found in the document entitled *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing* (Hinchee et al., 1992). This protocol document will serve as the primary reference for pilot test well designs and the detailed procedures to be used during the test.

2.0 SITE DESCRIPTION

2.1 Site B-371

2.1.1 History and Location

Site B-371 is an underground storage tank (UST) removal area located along Berman Road and adjacent to building 371 (Figure 1.1). There is limited

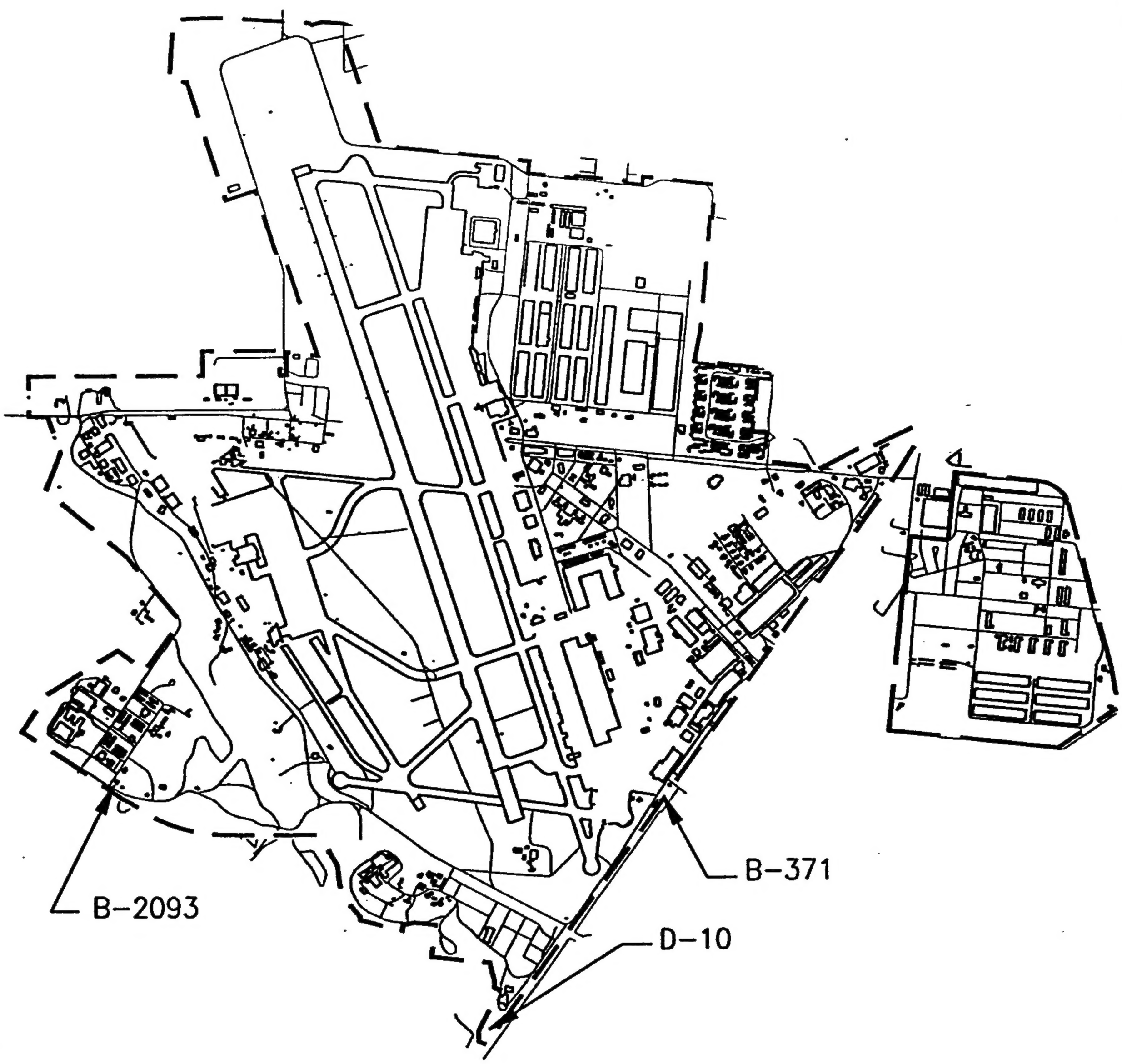


FIGURE 1.1
B-371, B-2093, D-10
SITE LOCATIONS

KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado

KELOC 12/3/93

information available regarding the history of the site. The information provided in this section was included in the decision document for the site (Kelly AFB, 1990). The B-371 site consisted of five 25,000-gallon USTs. The B-371 tank farm was constructed in 1943 and was used as a hydrant fueling system until its closure in 1986. The subject tanks were registered as inactive tanks with the Texas Water Commission (TWC) as of 1984. There was no record or history of releases noted in the decision document (Kelly AFB, 1990).

Subsurface soil sampling of two borings drilled at site B-371 indicated BTEX concentrations ranging from 690 to 3,046 ppb and petroleum hydrocarbons ranging from nondetect to 40 parts per million (ppm) (PSI, 1991). Total petroleum hydrocarbons (TPH) levels detected from samples collected along tank side walls ranged from 52 to 1,380 ppm, and averaged 227 ppm (PSI, May 1991). The location of the side wall samples were not presented. The boring locations are shown on Figure 3.1.

2.1.2 Site Geology

The soils at this site are comprised of tan, silty sand fill material from the surface to a depth of approximately 9 feet in boring B-1 and to 1 foot below ground surface (bgs) in boring B-2 (IHS, 1991). Beneath this fill material lies a stiff, silty clay with calcareous gravel to a depth of approximately 24 feet below grade, where the soil profile transitions into the tan, gray clays of the Navarro Formation. A thin interval of hard, dry cherty gravel lies just above the Navarro clays. No water was reported in the two boring logs (IHS, 1991). Groundwater was found in nearby wells at 13.5 feet bgs (ES, 1993).

2.1.3 Site Contaminants

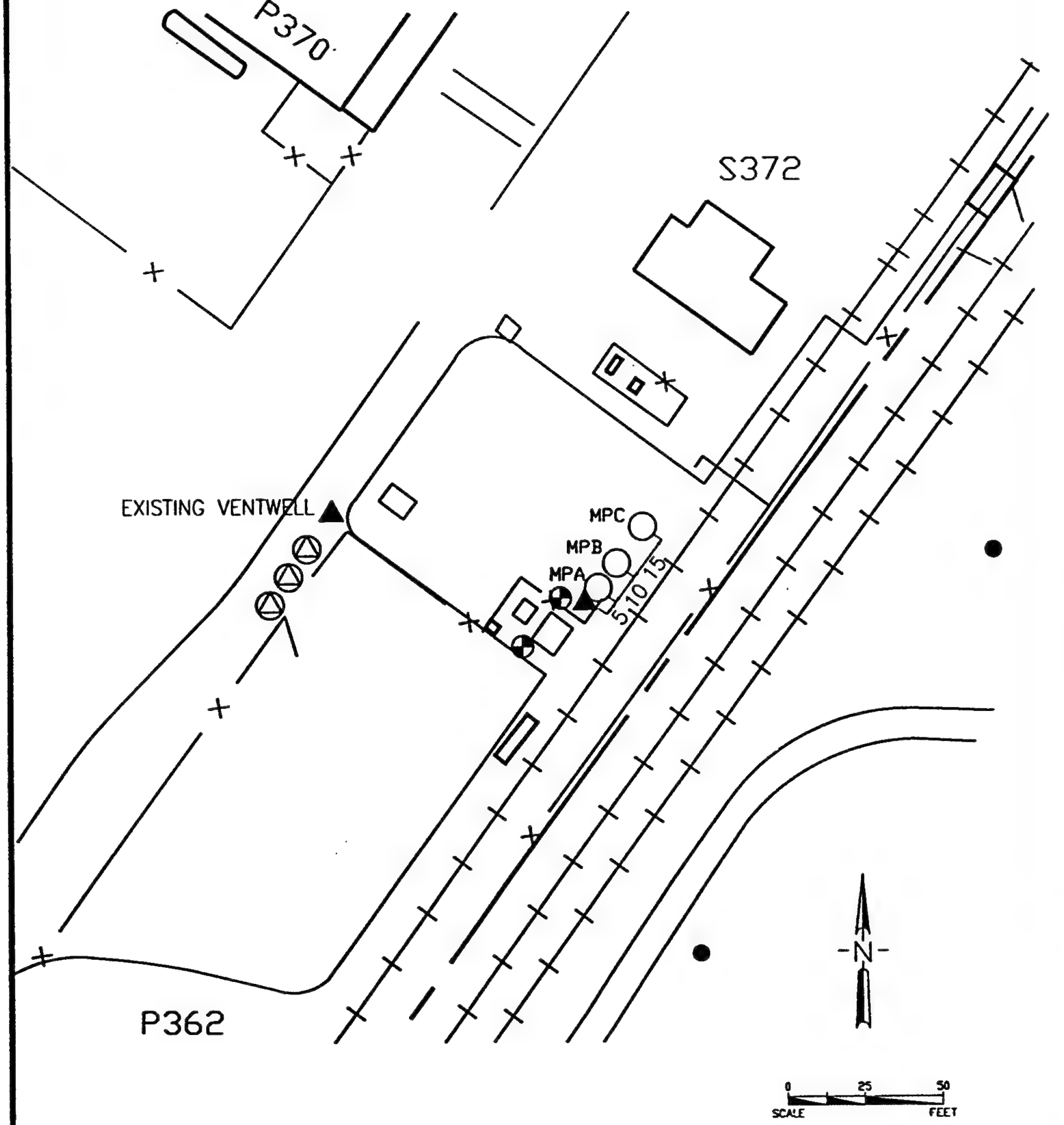
The primary contaminants at the site are petroleum hydrocarbon residuals which have likely been released from hydrant fuel stored in the tanks at the former UST facility at building 371. Samples were collected in the silty clay soils beneath the fill material. No explanation for this sampling selection was provided (PSI, May 1991).

2.2 Site B-2093

2.2.1 History and Location

Site B-2093 is a former automobile service center and gasoline station. Three 10,000-gallon underground fuel tanks were excavated along with all associated piping. The date of the tank excavation was not provided.

Three separate investigations were conducted in 1990, 1991 and 1992. Subsurface soil sampling of borings drilled near the excavated tanks indicated BTEX and TPH contamination (Chen-Northern, 1990). Samples collected from the piping trenches showed TPH levels ranging from 55 ppm to 213 ppm (SWL, 1992). An investigation conducted in 1992 installed and sampled two soil borings and five monitoring wells. BTEX was detected in soils at a depth of 15 to 18 feet in MW7 and semivolatile compounds were detected at 23 feet at MW9. BTEX was detected in the groundwater (Haliburton NUS, 1993).



LEGEND

VENT WELL

MONITORING POINT

EXISTING MONITORING POINT

SOIL BORING

FIGURE 3.1
SITE B-371
PROPOSED VENT WELL /
MONITORING WELL LOCATIONS
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado
ES

B370 12/3/93

2.2.2 Site Geology

The surface area of the B-2093 site is covered by asphalt or a thin topsoil layer. Gravelly clay fill was found at depths ranging from 1.5 to 3 feet below ground surface. The fill material was underlain by the Navarro clay, which is tan, greenish-blue-gray silty clay. The clay was moist and stiff to hard. The borings constructed in 1990 were drilled to approximately 30 feet. No noticeable groundwater was encountered while drilling (Chen-Northern, 1990). Groundwater wells installed in 1989 indicated groundwater appeared to be under confined conditions beginning at approximately 30 feet bgs (Chen-Northern, 1990). The monitoring wells installed in 1992 were drilled to depths ranging from 25 to 45 feet (Haliburton NUS, 1993). The water level elevations varied as much as seven feet between 1990 and 1993.

2.2.3 Site Contaminants

The primary contaminants at the site are residual fuel components which have likely been released from the fuel tanks. The soil borings around the tank pit were sampled at 2.5 foot intervals to 15 feet and at 5 foot intervals to 30 feet. Xylene was detected in two borings at concentrations ranging from 1.1 to 390 mg/kg. The highest concentrations were found 12.5 and 15 feet below ground surface on the north side of the excavation. The TPH concentrations ranged from 7 to 31 mg/kg (Chen Northern, 1990). Three samples were collected from trenches along the distribution lines. One sample collected near the east dispenser had a total BTEX concentration of 4.8 mg/kg. The samples collected from the east, west, and north dispensers contained TPH concentrations of 55, 151, and 213 mg/kg, respectively (SWL, 1992). Complete soil sample results were not included in the Haliburton NUS report. BTEX was detected in samples from one well at a depth of 15 to 18 feet below ground level (Haliburton NUS, 1993).

2.3 Site D-10

2.3.1 History and Location

Site D-10 consists of two distinct disposal areas near the base asphalt storage yard. The first area is a waste tar disposal area, located in a gully and is approximately 200 feet by 35 feet by 8 feet deep. The second disposal area is an oily waste residue which covers an area 14 feet by 100 feet with an average depth of 2 feet. Contaminated soils were noted while drilling monitoring wells outside of the actual disposal area near the asphalt storage shed.

The contaminated soils were discovered in 1986 as a result of a citizen complaint concerning an asphalt spill. The waste for deposit was originally thought to be outside the base boundary but was later confirmed to be on base property.

2.3.2 Site Geology

The acid tar waste is located in a gully. Groundwater is approximately 13 to 14 feet below ground surface. The surface soils at MW1 are primarily fill to approximately 10 feet below ground surface. Below the fill consists of a black gravelly clay. In the gully area, the soils are brown clayey sands which increase in clay

with depth. A dense gravel mixed with sand and clay begins 10 to 13 feet bgs. The monitoring wells installed in 1987 were drilled to depths ranging from 23 to 25 feet.

2.3.3 Site Contaminants

The waste tar is acidic with a pH of <2. The site contaminants include: TPH range from 400 mg/kg to 140,000 mg/kg, PCBs (maximum 6 mg/kg), and naphthalene (maximum 29 ppm). Other compounds detected at the site include DDE (0.06 mg/kg); DDT (0.12 mg/kg) and BTEX.

3.0 PILOT TEST ACTIVITIES

The purpose of this section is to describe the pilot test activities to take place at sites B-371, B-2093, and D-10. The proposed locations and construction details for the central VWs and vapor MPs are discussed. Criteria for locating a suitable background well position are outlined. Soil and soil gas sampling procedures and the blower configuration that will be used to inject air (oxygen) into contaminated soils are also discussed in this section. Finally, a brief description of the pilot test procedures is provided.

The bioventing technology is intended to remediate contamination only in the unsaturated zone. Therefore, pilot test activities will be confined mainly to unsaturated soils. The central VW will be completed at the depth of contamination. If contamination extends throughout the unsaturated zone, the central VWs may be completed to approximately 2 or 3 feet below the current groundwater table to provide oxygen to the deepest levels of the unsaturated zone. This construction also provides oxygen to deep levels in case the groundwater table recedes due to pressurization or natural fluctuation. No dewatering will take place during the pilot tests. Existing monitoring wells will not be used as primary air injection or vapor monitoring wells. However, monitoring wells which have a portion of their screened interval above the water table may be used as vapor MPs or to measure the composition of background soil gas. Additionally, a soil gas survey may be performed to locate the most oxygen depleted, therefore the most contaminated, area of the site. This information will aid in selecting final placement of the pilot test system.

3.1 Bioventing Test Design for Site B-371

A general description of criteria for siting a central VW and vapor MPs are included in the protocol document (Hinchee et al., 1992). Final determination of the need for bioventing at this location will be based on the results of soil gas samples collected prior to drilling. Figure 3.1 illustrates the proposed locations of the central VW and MPs at this site. The final locations may vary slightly from those proposed if significant fuel contamination is not observed in the boring for the central VW. Based on available information the central VW should be located near the back of the former tank area along the railroad tracks. Soils in this area are expected to be TPH contaminated and oxygen depleted (<2 percent), and biological activity should be stimulated by oxygen-rich soil gas ventilation during pilot test operations. Soils in this area are not expected to be influenced by the VW at the nearby B-370 site.

Due to the relatively shallow depth of contamination at this site and the potential for low permeability soils, the potential radius of venting influence around the central VW is expected to be 20 to 30 feet. Three vapor MPs (MPA, MPB, and MPC) will be located within a 30-foot radius of the central VW.

The VW will be constructed of 4-inch-diameter schedule 40 polyvinyl chloride (PVC), with a 10-foot interval of 0.04-inch slotted screen set at 5 to 15 feet bgs. Flush-threaded PVC casing and screen with no organic solvents or glues will be used. The filter pack will be clean, well-rounded silica sand with a 6 to 9 grain size and will be placed in the annular space to 1 foot above the screened interval. A 5-foot layer of bentonite will be placed directly over the filter pack. The first 6 inches of bentonite will consist of bentonite pellets hydrated in place with potable water. This layer of pellets will prevent the addition of bentonite slurry from saturating the filter pack. The remaining 54 inches of bentonite will be fully hydrated and mixed aboveground, and the slurry will be placed into the annular space to produce an air-tight seal above the screened interval. The borehole will then be completed to the ground surface with a bentonite/cement grout. A complete seal is critical to prevent injected air from short-circuiting to the surface during the bioventing test. Figure 3.2 illustrates the proposed central VW construction detail for this site.

A typical multi-depth vapor MP installation for this site is shown in Figure 3.3. Soil gas oxygen and carbon dioxide concentrations will be monitored at depths of 6 feet, and 12 feet at each location. Multi-depth monitoring will confirm that the entire soil profile is receiving oxygen and will be used to measure fuel biodegradation rates at the three depths. The annular spaces between the three screened MP intervals will be sealed with bentonite to isolate the monitoring intervals. As with the central VW, several inches of bentonite pellets will be used to shield the filter pack from rapid infiltration of bentonite slurry additions. Additional details on VW and MP construction are presented in section 4 of the protocol document (Hinchee et al., 1992).

3.2 Site B-2093

Figure 3.4 illustrates the proposed locations of the central VW and MPs at this site. The final location of these wells may vary slightly from the proposed location if significant fuel contamination is not observed in the boring for the central VW. Based on site investigation data, the central VW should be located near MW1, north of the service islands canopy, near the former tank area. This area is expected to have an average TPH concentration exceeding 20 mg/kg and elevated BTEX concentrations. Soils in this area are expected to be oxygen depleted (<2 percent), and biological activity should be stimulated by oxygen-rich soil gas ventilation during pilot test operations.

Due to the relatively shallow depth of contamination at this site and the potential for low permeability soils, the potential radius of influence around the central VW is expected to be 20 to 30 feet. Three vapor MPs (MPA, MPB, and MPC) will be located within a 30 feet radius of the central VW.

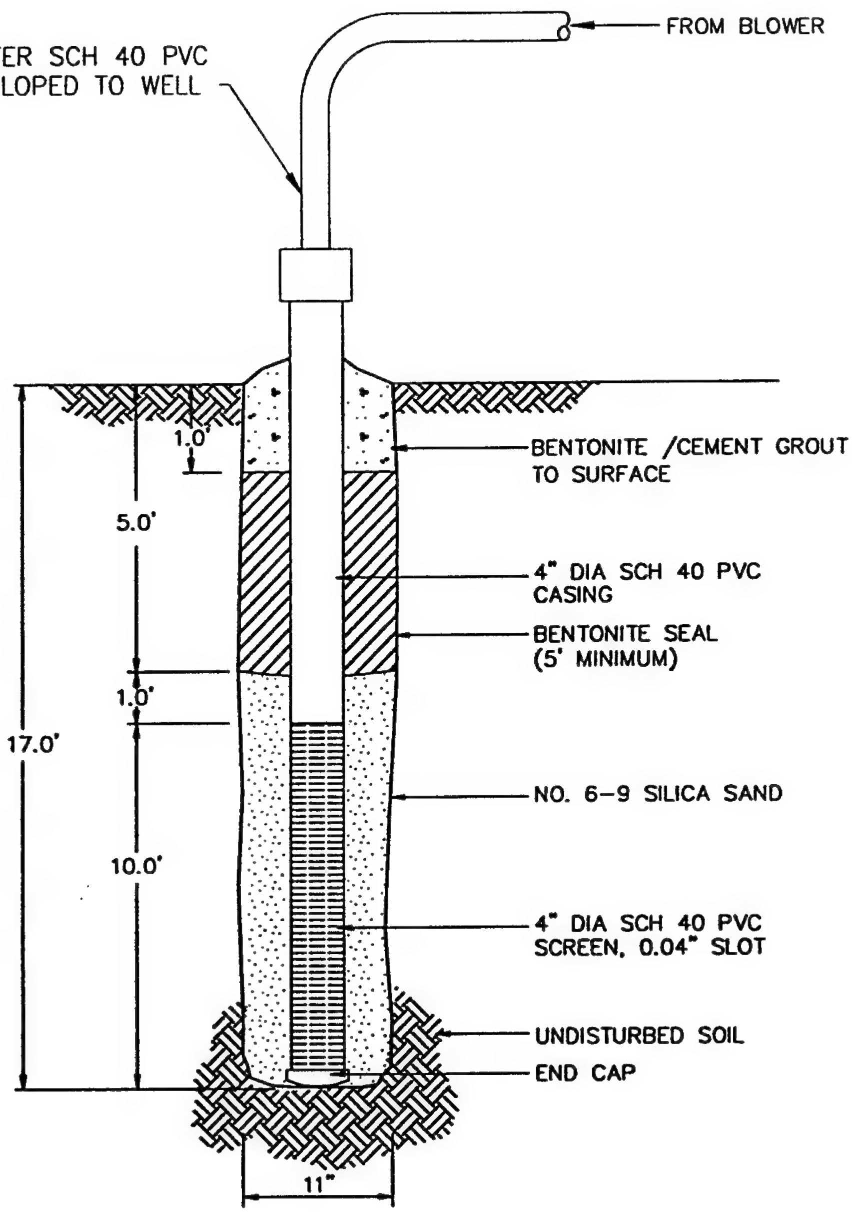


FIGURE 3.2
INJECTION VENT WELL
CONSTRUCTION DETAIL
SITE B-371
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado

TYPWELL 12/9/93

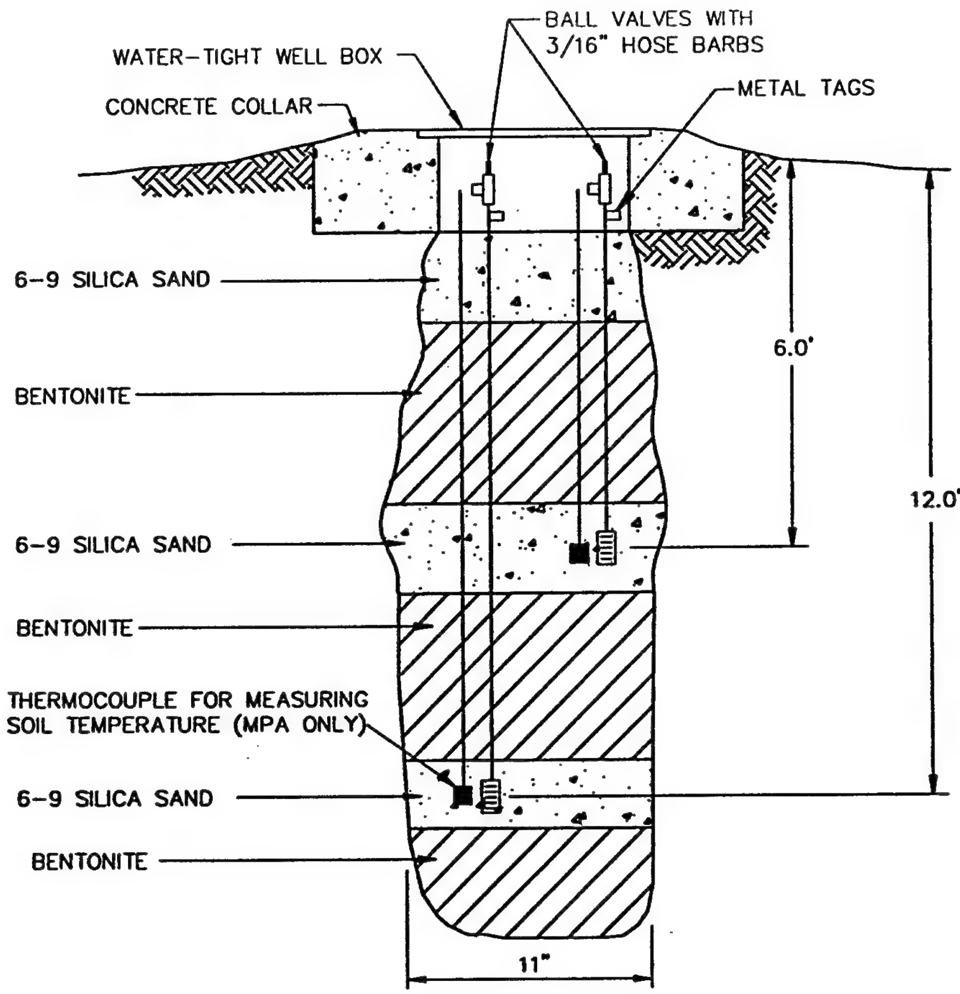


FIGURE 3.3
MONITORING POINT
CONSTRUCTION DETAIL
SITE B-371
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado

TYPWELL 12/8/93

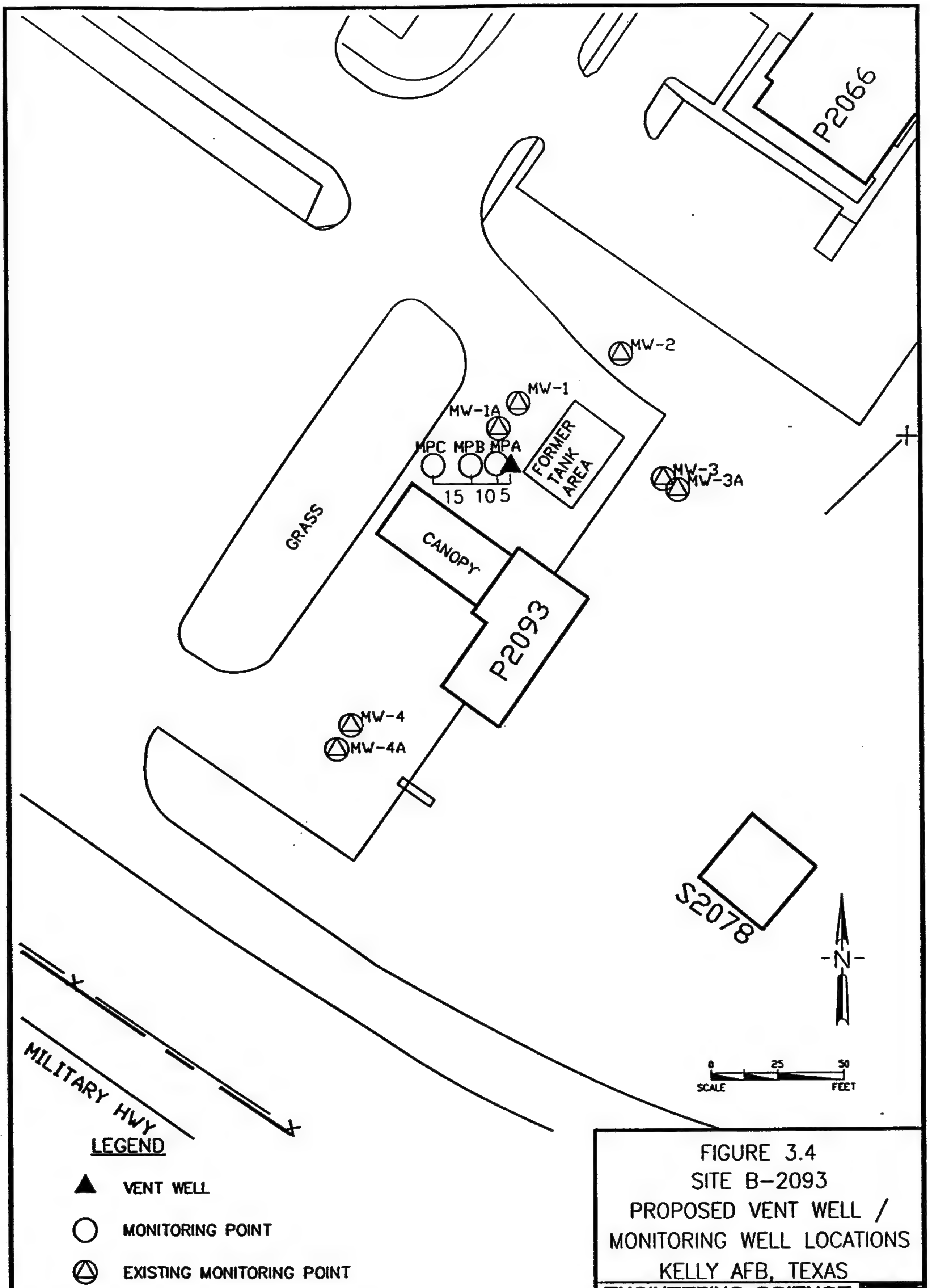


FIGURE 3.4
SITE B-2093
PROPOSED VENT WELL / MONITORING WELL LOCATIONS
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado

B2093 12/3/93

The VW will be constructed of 4-inch diameter schedule 40 PVC, with a 12-foot interval of 0.04-inch slotted screen set at 15 to 30 feet bgs. Flush-threaded PVC casing and screen with no organic solvents or glues will be used. The filter pack will be clean, well-rounded silica sand with a 6 to 9 grain size and will be placed in the annular space to 1 foot above the screened interval. A 5-foot layer of bentonite will be placed directly over the filter pack. The first 6 inches of bentonite will consist of bentonite pellets hydrated in place with potable water. This layer of pellets will prevent the rapid addition of bentonite slurry from saturating the upper portion of the filter pack. The remaining bentonite will be fully hydrated and mixed above-ground, and then placed into the annular space to produce an air-tight seal above the screened interval. A complete seal is critical to prevent injected air from short-circuiting to the surface during the bioventing test. The well will be completed to the ground surface with a bentonite/cement grout. Figure 3.5 illustrates the proposed central VW construction for this site.

A typical multi-depth vapor MP installation design for this site is shown in Figure 3.6. Soil gas oxygen and carbon dioxide concentrations will be monitored at depth intervals of 9 feet, 15 feet, and 21 feet at each location. Multi-depth monitoring will confirm that the entire soil profile is receiving oxygen, and will be used to measure fuel biodegradation rates at each depth. The annular spaces between the three monitoring intervals in each MP will be sealed with bentonite to isolate the intervals. As in the central VW, several inches of bentonite pellets will be used to shield the filter pack from rapid infiltration of bentonite slurry additions. Additional details on VW and MP construction are provided in section 4 of the protocol document.

3.3 Site D-10

Figure 3.7 illustrates the proposed locations of the central VW and MPs at this site. The final location of these wells may vary slightly from the proposed location if significant contamination is not observed in the boring for the central VW. Based on site investigation data, the central VW should be located near the asphalt storage building and south of MW1. This area is expected to have an average TPH concentration exceeding 8,000 mg/kg. Soils in this area are expected to be oxygen depleted (<2 percent), and biological activity should be stimulated by oxygen-rich soil gas ventilation during pilot test operations.

Due to the relatively shallow depth of contamination at this site and the potential for low permeability soils, the potential radius of influence around the central VW is expected to be 20 to 30 feet. Three vapor MPs (MPA, MPB, and MPC) will be located within a 30 feet radius of the central VW, a shown on Figure 3.4

The VW will be constructed of 4-inch diameter schedule 40 PVC, with a 12-foot interval of 0.04-inch slotted screen set at 13 to 5 feet bgs. Flush-threaded PVC casing and screen with no organic solvents or glues will be used. The filter pack will be clean, well-rounded silica sand with a 6 to 9 grain size and will be placed in the annular space to 1 foot above the screened interval. A 5-foot layer of bentonite will be placed directly over the filter pack. The first 6 inches of bentonite will consist of bentonite pellets hydrated in place with potable water. This layer of pellets will

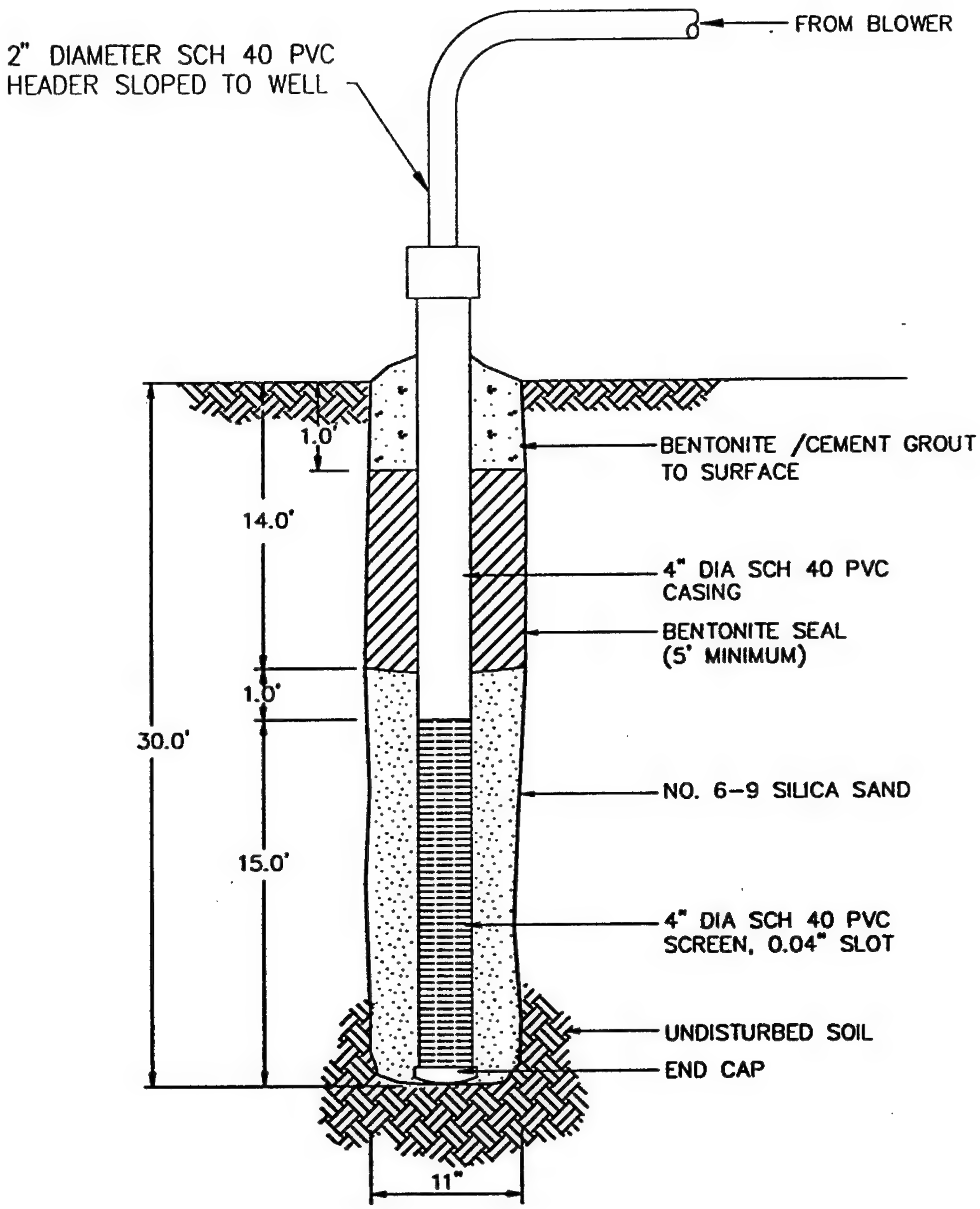


FIGURE 3.5
INJECTION VENT WELL
CONSTRUCTION DETAIL
SITE B-2093
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado
ES

TYPWELL 11/30/93

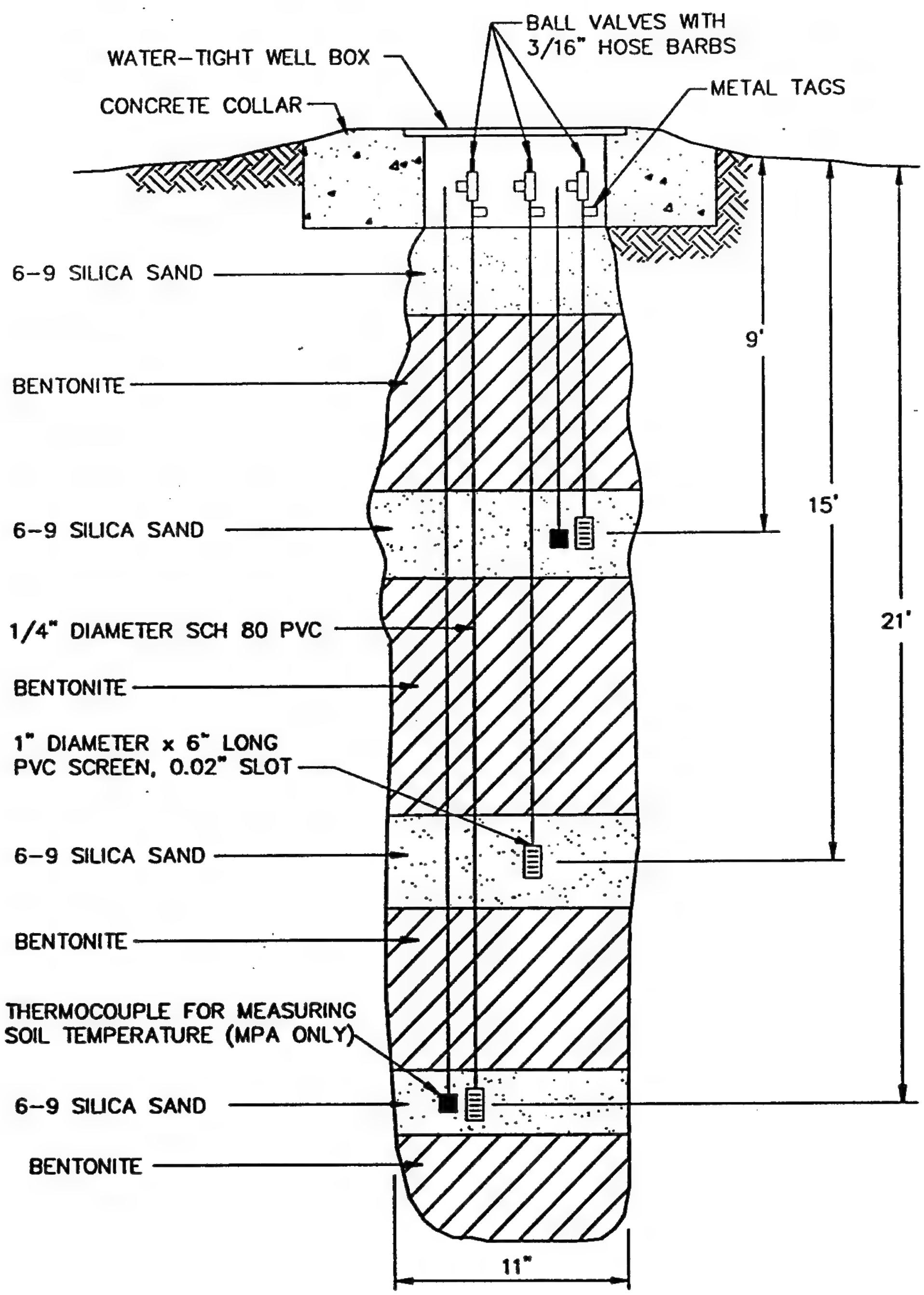


FIGURE 3.6
MONITORING POINT
CONSTRUCTION DETAIL
SITE B-2093
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado

ES

TYPWELL 12/3/93

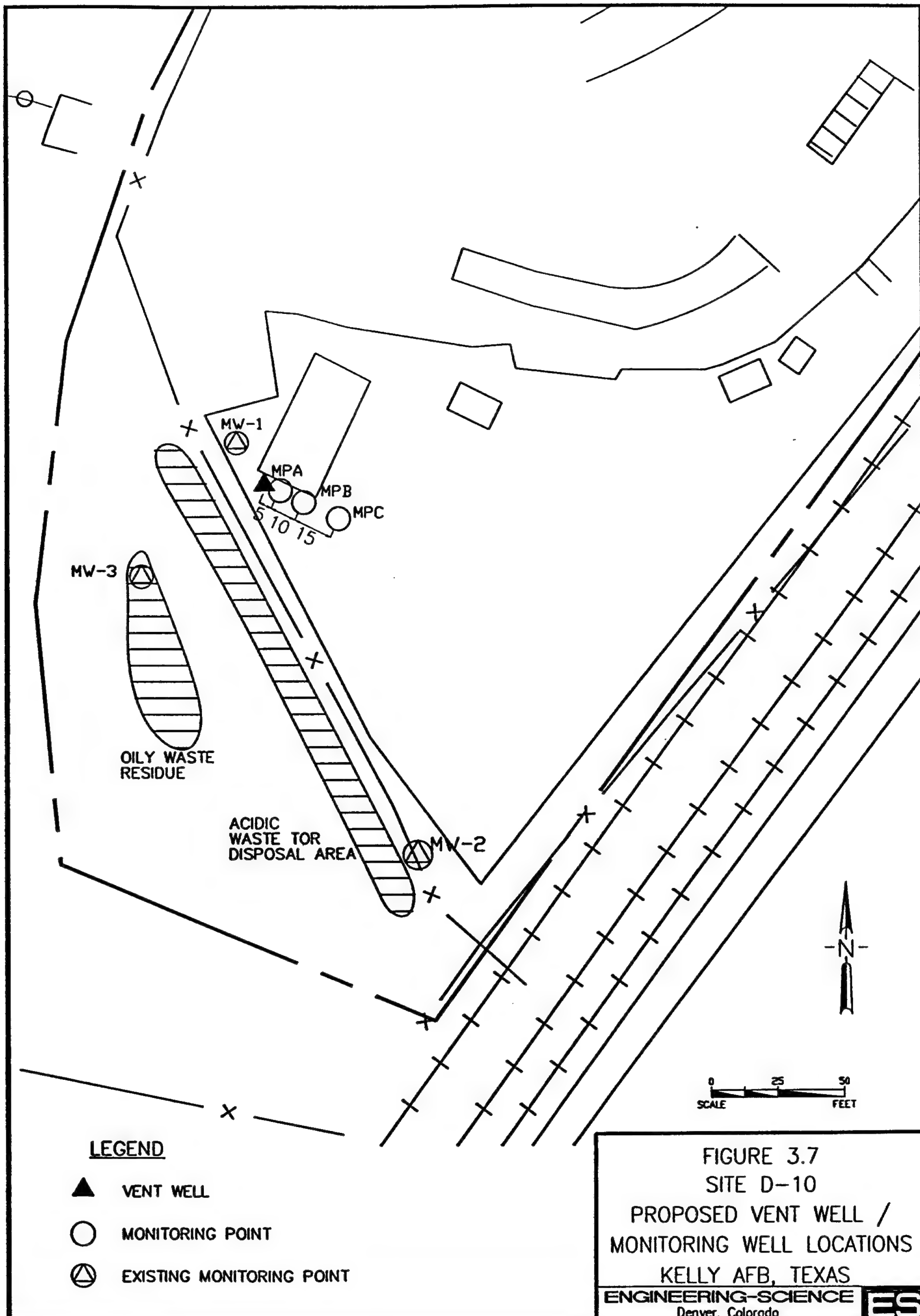


FIGURE 3.7
SITE D-10
PROPOSED VENT WELL /
MONITORING WELL LOCATIONS
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado
ES

STORAGE 12/3/93

prevent the rapid addition of bentonite slurry from saturating the upper portion of the filter pack. The remaining bentonite will be fully hydrated and mixed aboveground, and then placed into the annular space to produce an air-tight seal above the screened interval. A complete seal is critical to prevent injected air from short-circuiting to the surface during the bioventing test. The well will be completed to the ground surface with a bentonite/cement grout. Figure 3.8 illustrates the proposed central vent well construction for this site.

A typical multi-depth vapor MP installation design for this site is shown in Figure 3.9. Soil gas oxygen and carbon dioxide concentrations will be monitored at depth intervals of 4.5 feet, 8 feet, and 12 feet at each location. Multi-depth monitoring will confirm that the entire soil profile is receiving oxygen, and will be used to measure fuel biodegradation rates at each depth. The annular spaces between the three monitoring intervals in each MP will be sealed with bentonite to isolate the intervals. As in the central VW, several inches of bentonite pellets will be used to shield the filter pack from rapid infiltration of bentonite slurry additions. Additional details on VW and MP construction are provided in section 4 of the protocol document.

3.4 Background Well

The construction of an additional vapor MP may be required to measure background levels of oxygen and carbon dioxide and to determine if natural carbon sources are contributing to oxygen uptake during the *in situ* respiration test described in section 3.7. This background well would be installed in an area of uncontaminated soil and in the same stratigraphic formation as the MPs to be installed at the three sites. The background well would be similar in construction to the MPs (Figures 3.3, 3.6, and 3.9), and would be screened at two or more depths. ES will require some assistance from Kelly AFB in locating an appropriate position for the proposed background well.

Existing groundwater monitoring wells located in areas with no fuel contamination may be suitable for use as background wells. These wells must have a portion of their screened interval above the water table, and initial soil gas samples must contain oxygen in excess of 15 percent to be used as background wells. Additional information regarding background wells may be found in section 4.3 of the protocol document (Hinchee et al., 1992).

3.5 Handling of Investigation-Derived Wastes

Drill cuttings from all VW and MP borings will be collected in U.S. Department of Transportation approved containers. The containers will be labeled and placed in the Kelly AFB hazardous materials storage area. These drill cuttings will become the responsibility of Kelly AFB, and will be analyzed, handled, and disposed of in accordance with the current procedures for ongoing remedial investigations. This project is expected to generate less than two 55-gallon drums of cuttings per site (or six drums total).

Decontamination activities will take place in a designated wash pad area at Kelly AFB where decontamination waters can be flushed into existing drains in this

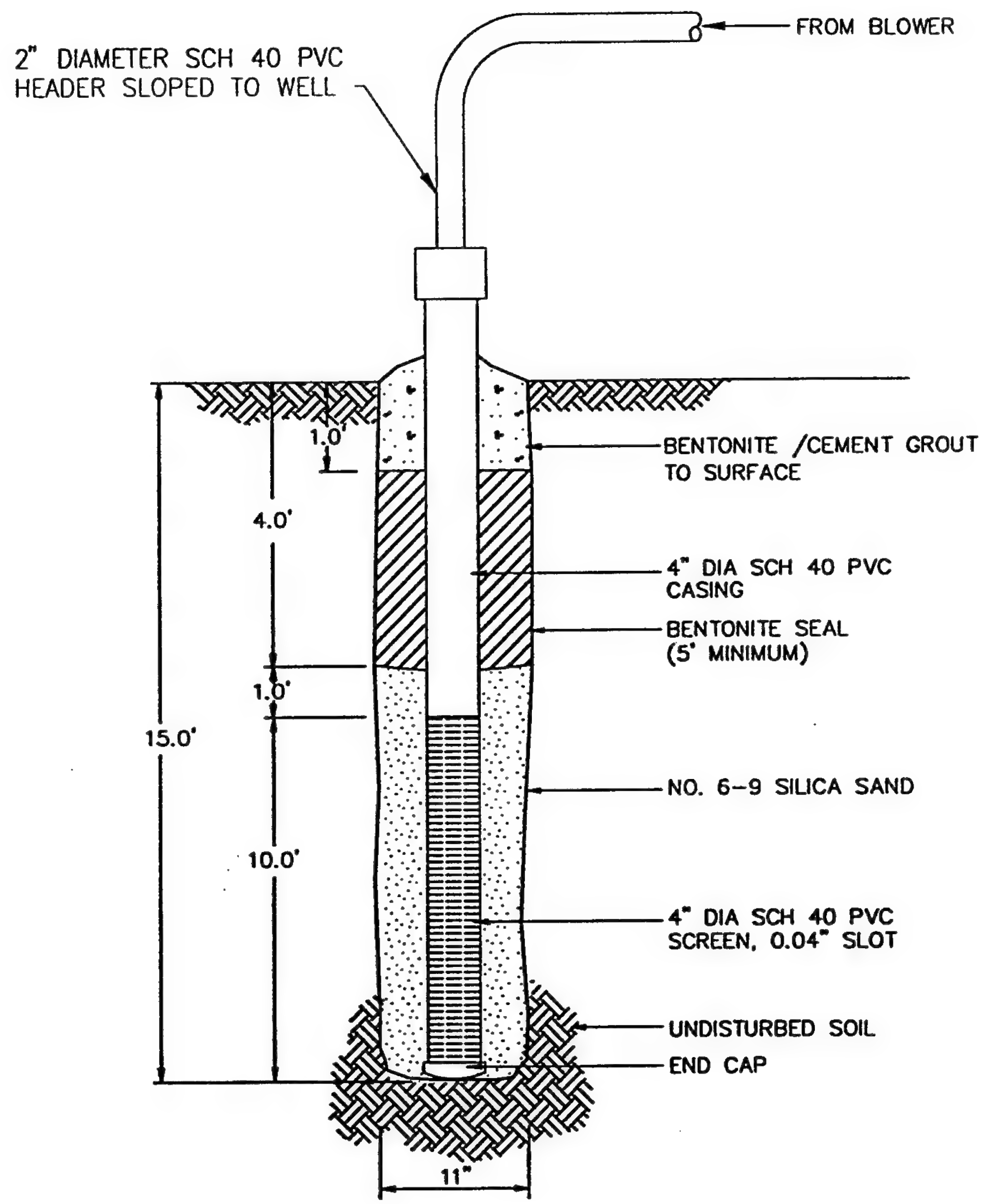


FIGURE 3.8
INJECTION VENT WELL
CONSTRUCTION DETAIL
SITE D-10
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado
ES

TYPWELL 12/3/93

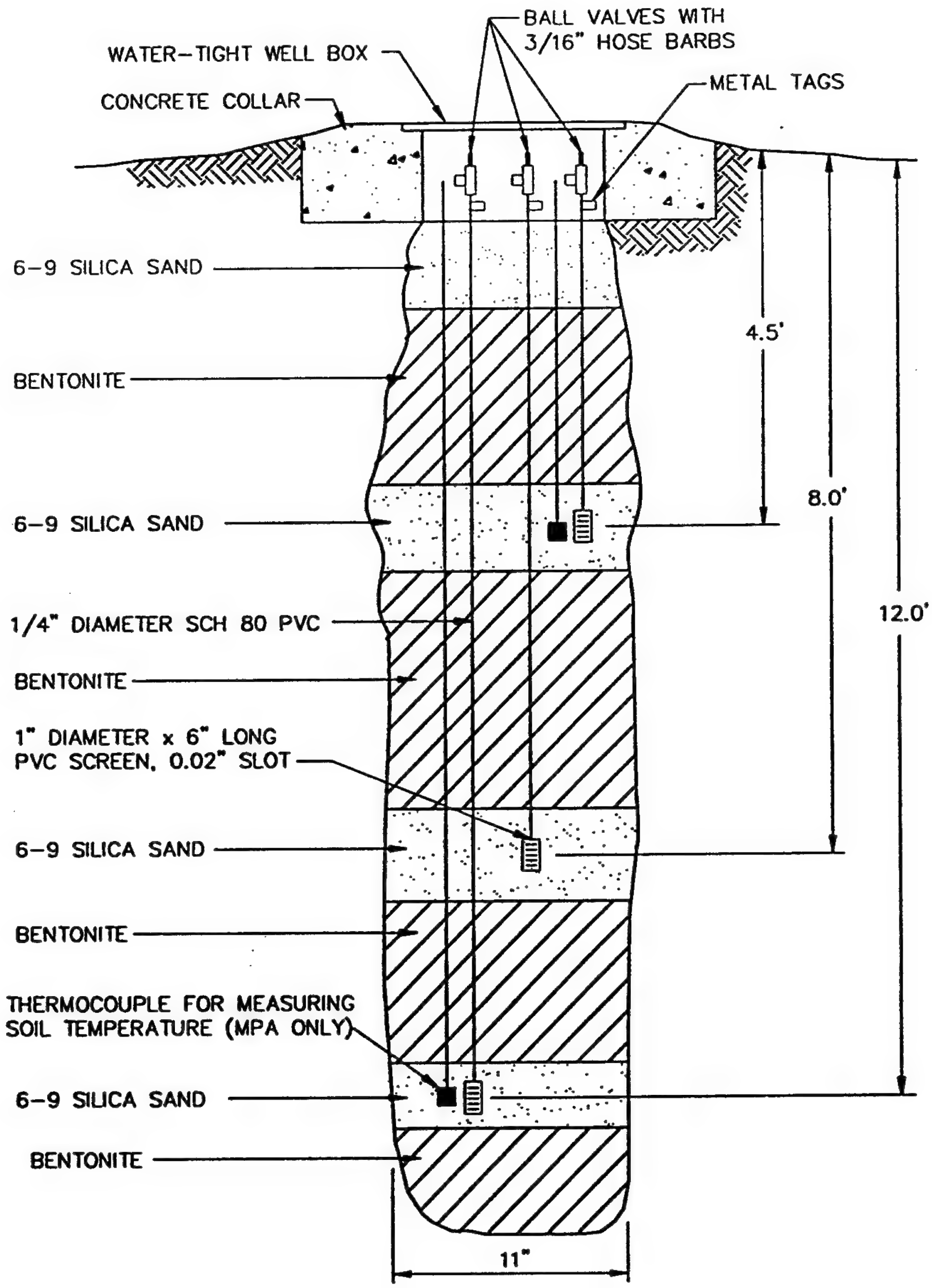


FIGURE 3.9
MONITORING POINT
CONSTRUCTION DETAIL
SITE D-10
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado

TYPWELL 11/30/93

area. Therefore, no containment of decontamination waters, other than that used to clean sampling tools, will be performed. These waters will be poured into the drains located at the washdown area.

3.6 Soil and Soil Gas Sampling

3.6.1 Soil Samples

Three soil samples will be collected from each pilot test area during the installation of the VW and MPs. Sampling procedures will follow those outlined in the protocol document. One sample will be collected from the most contaminated interval of each VW boring, and one sample will be collected from the interval of highest apparent contamination in each of the borings for the two MPs closest to the VW. Soil samples will be analyzed for TPH, BTEX, soil moisture, pH, particle sizing, alkalinity, total iron, and nutrients. One sample may need to be collected from a background, noncontaminated area for TKN (Kjehldahl nitrogen) analysis.

Samples for TPH and BTEX analysis will be collected using a split-spoon sampler containing brass tube liners. Soil samples collected in the brass tubes for TPH and BTEX analyses will be immediately trimmed, and the ends will be sealed with aluminum foil or Teflon® fabric held in place by plastic caps. Soil samples collected for physical parameter analyses will be placed in glass sample jars or other appropriate sample containers specified in the base sample handling plan. Soil samples will be labelled following the nomenclature specified in the protocol document (section 5), wrapped in plastic, and placed in a cooler maintained at a temperature of 4°C for shipment. A chain-of-custody form will be filled out, and the cooler will be shipped to Pace Laboratories, Inc., in Hunington Beach, California.

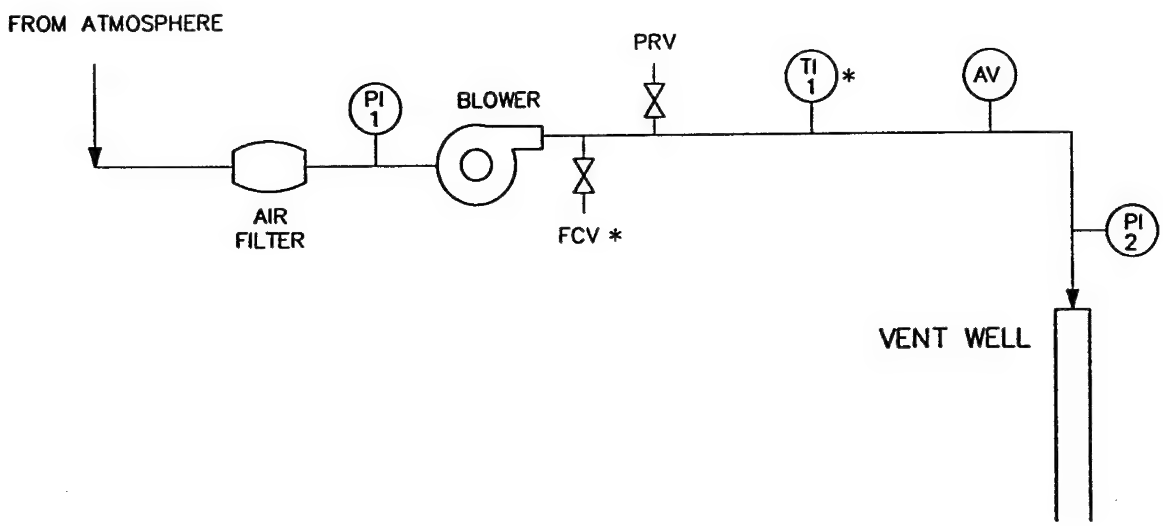
3.6.2 Soil Gas Samples

A total hydrocarbon vapor analyzer will be used during augering to screen split-spoon soil samples for intervals of high fuel contamination. Initial and final soil gas samples will be collected in SUMMA® cannisters in accordance with the Bioventing Field Sampling Plan (ES, 1992) from the VW and from the MPs closest to and furthest from the VW. Additionally, these soil gas samples will be used to predict potential air emissions, to determine the reduction in BTEX and total volatile hydrocarbons during the 1-year test, and to detect any migration of these vapors from the source area.

Soil gas sample canisters will be placed in a small cooler and packed with foam pellets to prevent excessive movement during shipment. Samples will not be sent on ice to prevent condensation of hydrocarbons. A chain-of-custody form will be filled out, and the cooler will be shipped to the Air Toxics Laboratory in Fulsom, California, for analysis.

3.7 Blower System

A 3-horsepower positive-displacement blower capable of injecting air at a flow rate of 20 to 40 standard cubic feet per minute (scfm) at a pressure of 8 pounds per square inch may be used to conduct the initial air permeability tests and *in situ* respiration tests. Figure 3.10 is a schematic of a typical air injection system used for



LEGEND

AV AIR VELOCITY GAUGE

PI 1 PRESSURE INDICATOR

TI 1 TEMPERATURE INDICATOR

FCV FLOW CONTROL VALVE

PRV PRESSURE RELIEF VALVE

* OPTIONAL

FIGURE 3.10
BLOWER SYSTEM
INSTRUMENTATION DIAGRAM
FOR AIR INJECTION
KELLY AFB, TEXAS

ENGINEERING-SCIENCE
Denver, Colorado

TYPWELL 11/30/93

pilot testing. The maximum power requirement anticipated for this pilot test is a 230-volt, single-phase, 30-amp service. Additional details on power supply requirements are described in section 5.0, Base Support Requirements.

3.8 In Situ Respiration Tests

The objective of the *in situ* respiration tests is to determine the rate at which soil bacteria degrade petroleum hydrocarbons. Respiration tests will be performed at every vapor MP where bacterial biodegradation of hydrocarbons is indicated by low oxygen levels and elevated carbon dioxide concentrations in the soil gas. Using a 1 scfm pump, air will be injected into each MP depth interval containing low levels (<2 percent) of oxygen. A 20-hour air injection period will be used to oxygenate local contaminated soils. At the end of the 20-hour air injection period, the air supply will be cut off, and oxygen and carbon dioxide levels will be monitored for the following 48 to 72 hours. The decline in oxygen and increase in carbon dioxide concentrations over time will be used to estimate rates of bacterial degradation of fuel residuals. Helium will also be injected at one or two MPs to estimate oxygen diffusion rates in site soils. This estimated rate of diffusion will be used to separate oxygen diffusion and biodegradation components of the measured rate of oxygen consumption. Additional details on the *in situ* respiration test procedures are provided in section 5.7 of the protocol document (Hinchee et al., 1992).

3.9 Air Permeability Tests

The objective of the air permeability tests is to determine the extent of the subsurface that can be oxygenated using the VW. Air will be injected into the 4-inch-diameter VW using the blower unit, and pressure response will be measured at each MP with differential pressure gauges to determine the region influenced by the unit. Oxygen will also be monitored in the MPs to ascertain whether oxygen levels in the soil increase as the result of air injection. One air permeability test lasting 4 to 8 hours will be performed at each site.

3.10 Extended Pilot Test Bioventing System

Extended, 1-year bioventing systems will also be installed at each site. At each site where power is not already available, the base will be requested to provide a power pole with a 230-volt, single-phase, 30-amp breaker box, one 230-volt receptacle, and two 115-volt receptacles. A licensed electrician subcontracted to ES will assist in wiring the blowers to line power. The blowers will be housed in small, prefabricated sheds to provide protection from the weather.

The systems will be in operation for 1 year, and every 6 months ES personnel will conduct *in situ* respiration tests to monitor the long-term performance of this bioventing system. Weekly system checks will be performed by Kelly AFB personnel. If required, major maintenance of the blower unit may be performed by ES Austin personnel. Detailed blower system information and a maintenance schedule will be included in the operation and maintenance (O&M) manual provided to the base. More detailed information regarding the test procedures can be found in the protocol document.

4.0 EXCEPTIONS TO PROTOCOL PROCEDURES

The procedures that will be used to measure the air permeability of the soil and *in situ* respiration rates are described in sections 4 and 5 of the protocol document (Hinchee et al., 1992). No exceptions to the protocol procedures are anticipated.

5.0 BASE SUPPORT REQUIREMENTS

The following base support is needed prior to the arrival of the drilling subcontractor and the ES pilot test team:

- Assistance in obtaining drilling and digging permits.
- Assistance in finding a suitable location for the background well. The background well location should be in an area with no fuel contamination and with similar stratigraphy to that of the sites. Preferably, 110-volt receptacle power will be available within 150 feet of the background well location.
- Installation of power poles at site B-371 and site D-10 and confirmation that power is available at site B-2093. Each site should have 230-volt, 30-amp, single-phase service. ES will provide a breaker box with one 230-volt receptacle and two 115-volt receptacles. The power should be located within 10 to 15 feet of the central VW location at each site.
- Provision of any paperwork required to obtain gate passes and security badges for approximately three ES employees, two drillers, and an electrician. Vehicle passes will be needed for one truck and a drill rig.

During the initial testing, the following base support is needed:

- A decontamination pad where the driller can clean augers between borings.
- Acceptance of responsibility by Kelly AFB for drill cuttings from VW and MP borings, including any drum sampling to determine hazardous waste status.
- Twelve square feet of desk space and a telephone in a building located as close to the site as practicable.
- The use of a facsimile machine for transmitting fifteen to twenty pages of test results.

During the 1-year extended pilot test, base personnel will be required to perform the following activities:

- Check the blower system once per week to ensure that it is operating and to record the air-injection pressure and temperature. Change air filters and blower lubricants when required. ES will provide a brief training session on these procedures and an O&M manual.
- If the blower stops working, notify Mr. Brian Vanderglas or Mr. Doug Downey, ES-Denver, at (303) 831-8100, or Mr. Jerry Hansen, AFCEE, at (512) 536-4331.

- Arrange site access for an ES technician to conduct *in situ* respiration tests approximately 6 months and 1 year after the initial pilot test.

6.0 PROJECT SCHEDULE

The following schedule is contingent upon timely approval of this pilot test work plan.

Event	Date
Draft test work plan to AFCEE/Kelly AFB	10 December 1993
Notice to proceed	20 December 1993
Begin initial pilot tests	5 January 1994
Complete initial pilot tests	26 January 1994
Interim results report	30 March 1994
Second respiration tests	6 June 1994
Final respiration tests	6 December 1994
Final results report	29 December 1994

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Hinchee, R.E., S.K. Ong, R.N. Miller, D.C. Downey, and R. Frandt. January 1992. "Test Plan and Technical Protocol for a Field Treatability Test for Bioventing."

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DRAFT

Part II

Draft Interim Pilot Test Results Report for Site B-2093 and Site D-10 Kelly AFB, Texas

Prepared for

Air Force Center for Environmental Excellence
Brooks AFB, Texas
and

Kelly Air Force Base
San Antonio, Texas

Prepared by

Engineering-Science, Inc.
Austin, Texas

April 1994

CONTENTS

FIGURES

TABLES

PART II

DRAFT
INTERIM PILOT TEST RESULTS REPORT
SITE B-2093 AND SITE D-10
KELLY AFB, TEXAS

Initial bioventing pilot tests were completed at site B-2093 and site D-10 at Kelly Air Force Base (AFB), Texas, during the period of 15 December 1993 through 22 January 1994. A third site was tentatively planned at the B-371 underground storage tank (UST) removal area along Berman Road. This site was not tested because of logistical problems due to underground utilities (gas line), the rail line, and proximity to sandy backfill material from UST excavation. The purpose of this Part II report is to describe the results of the initial pilot tests at site B-2093 and site D-10 and to make specific recommendations for extended testing to determine the long-term impact of bioventing on site contaminants. Descriptions of the history, geology, and contamination at each site are contained in Part I, the Bioventing Pilot Test Work Plan.

1.0 SITE B-2093

1.1 Pilot Test Design and Construction

Installation of an air injection vent well (VW) and three vapor monitoring points (MPs) at site B-2093 began on 7 January 1994, and was completed on 9 January 1994. Drilling services were provided by Jones Environmental Drilling, Inc., of San Antonio, Texas. Well installation and soil sampling were directed by Brian Vanderglas, the Engineering-Science, Inc. (ES) site manager, and Susan Roberts, the ES site geologist. The following sections describe the final design and installation of the bioventing system at this site.

One VW, three MPs (MPA, MPB, and MPC), and a blower unit were installed at site B-2093. Figures 1.1 and 1.2, respectively, depict the locations of and hydrogeologic cross sections for the VW and MPs completed at site B-2093. A background MP was not installed at site B-2093 because there were no known areas of uncontaminated soil at the site accessible for drilling. Therefore, data from the background MP installed at site FC-2 for a separate pilot test at Kelly AFB, was also applied to site B-2093.

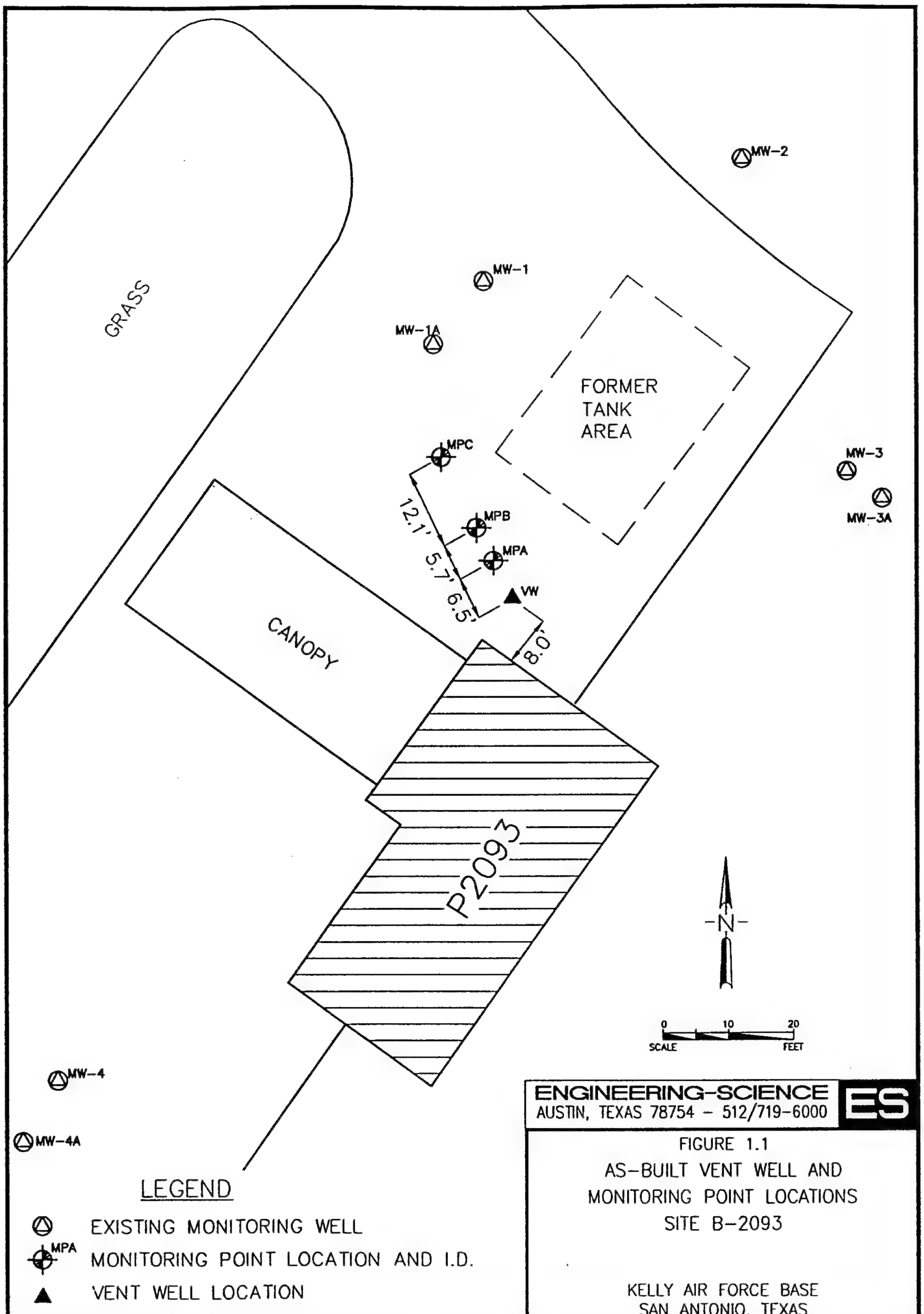

FIGURE 1.1
AS-BUILT VENT WELL AND MONITORING POINT LOCATIONS
SITE B-2093

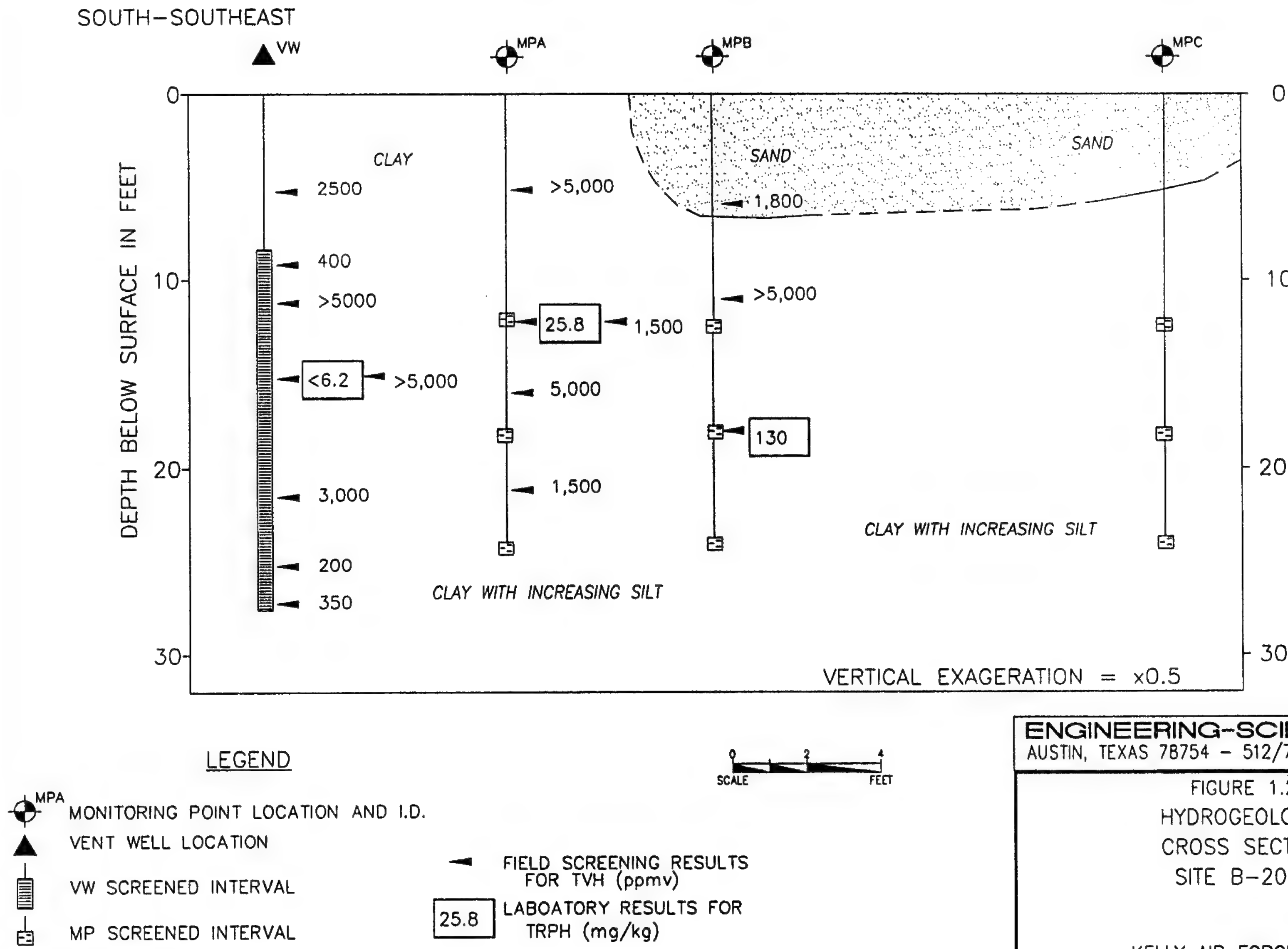

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FIGURE 1.2
HYDROGEOLOGIC
CROSS SECTION
SITE B-2093

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

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1.1.1 Air injection vent well

The air injection VW was installed following procedures described in the Air Force Center for Environmental Excellence (AFCEE) bioventing protocol document (Hinchee et al., 1992*). Figure 1.3 shows construction details for the VW. The VW was installed in a tight clay formation that contained hydrocarbon contamination at all sampling locations and depths. Groundwater was not encountered during drilling, but groundwater was present in the VW a few days after construction at approximately 21 feet below ground surface (bgs). By 9 March 1994, the groundwater level had risen to about 5 feet bgs. The VW was constructed using 4-inch-diameter, schedule 40 polyvinyl chloride (PVC) casing, with 20 feet of 0.04-inch slotted PVC screen installed from approximately 8 to 28 feet bgs. The annular space between the well casing and borehole was filled with 6-9 silica sand from the bottom of the borehole to approximately 1 foot above the well screen. Approximately 5.5 feet of granular bentonite was placed above the sand in 6-inch lifts, with each lift being hydrated in place. On top of the bentonite layer, approximately 1.5 feet of concrete was placed and was finished flush with the existing asphalt surface. The well casing was cut off approximately 2 feet above the surface, and a slip cap was temporarily placed on the top of casing. Eventually, a positive displacement blower will be installed at the site.

1.1.2 Monitoring points

At site B-2093, the MP screens were installed at 12.0-, 18.0-, and 24.0-foot depths. The three MPs (MPA, MPB, and MPC) were constructed as shown in Figures 1.2 and 1.4. Each MP monitoring interval was constructed using a 6-inch section of 1-inch-diameter PVC well screen and a 0.25-inch-diameter schedule 80 PVC riser pipe extending to the ground surface. At the top of each riser, a ball valve and a 3/16-inch hose barb were installed. The top of each MP was completed with a flush-mounted metal well protector set in a concrete base. Thermocouples were installed at the 12.0- and 24.0-foot depths at MPA to measure soil temperature. The existing groundwater monitoring wells (MWs) at the site could not be used as soil gas MPs because either the screened interval was below the groundwater surface or the tight soils prevented soil gas sampling in two tested MWs (MW-1 and MW-4).

1.1.3 Blower unit

During the initial pilot test, a portable 3-horsepower (hp) Roots® 22U-RAI positive-displacement (PD) blower unit was used. The tight clay conditions at site B-2093 prevented the initial collection of representative soil gas samples from any of the MPs and the VW. The 3 hp Roots PD blower was set up to inject air into the VW at the site in an attempt to determine if pressure responses could be attained in the MPs and to possibly loosen the low-permeability clay to permit air (oxygen) flow through the contaminated profile. The trailer-mounted unit was energized by 208-

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* Hinchee, R.E., S.K. Ong, R.N. Miller, D.C. Downey, and R. Frandt. *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing.* January 1992.

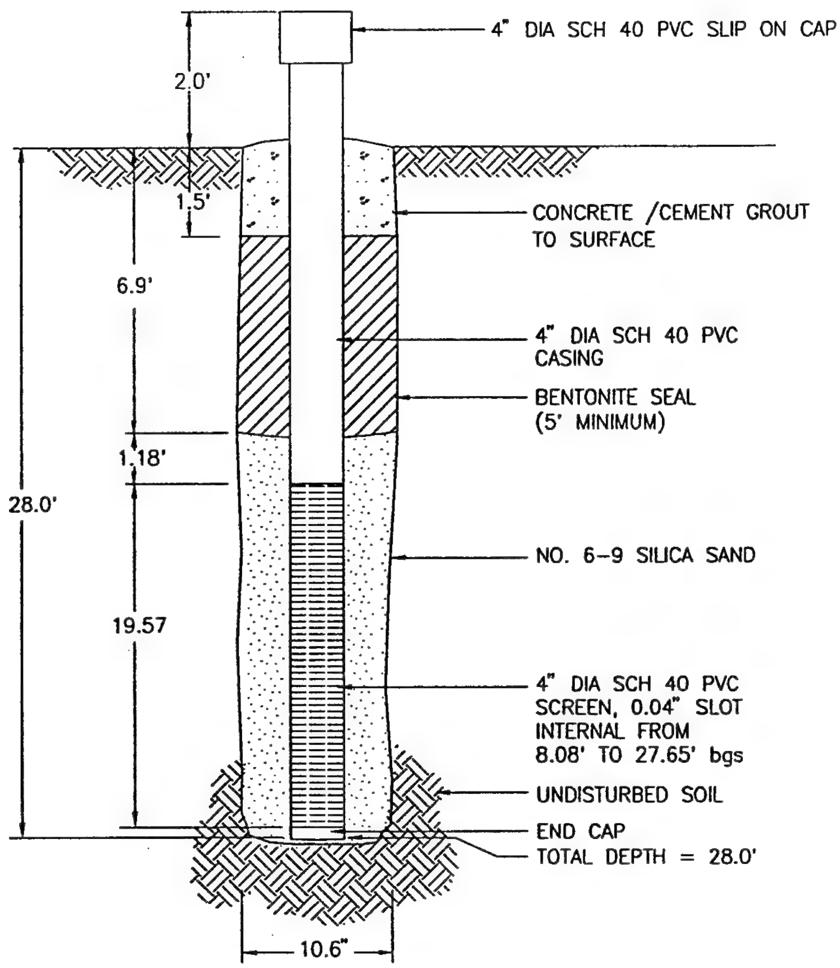

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FIGURE 1.3
AS-BUILT INJECTION VENT WELL
CONSTRUCTION DETAIL
SITE B-2093

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

DETKE 3/11/94

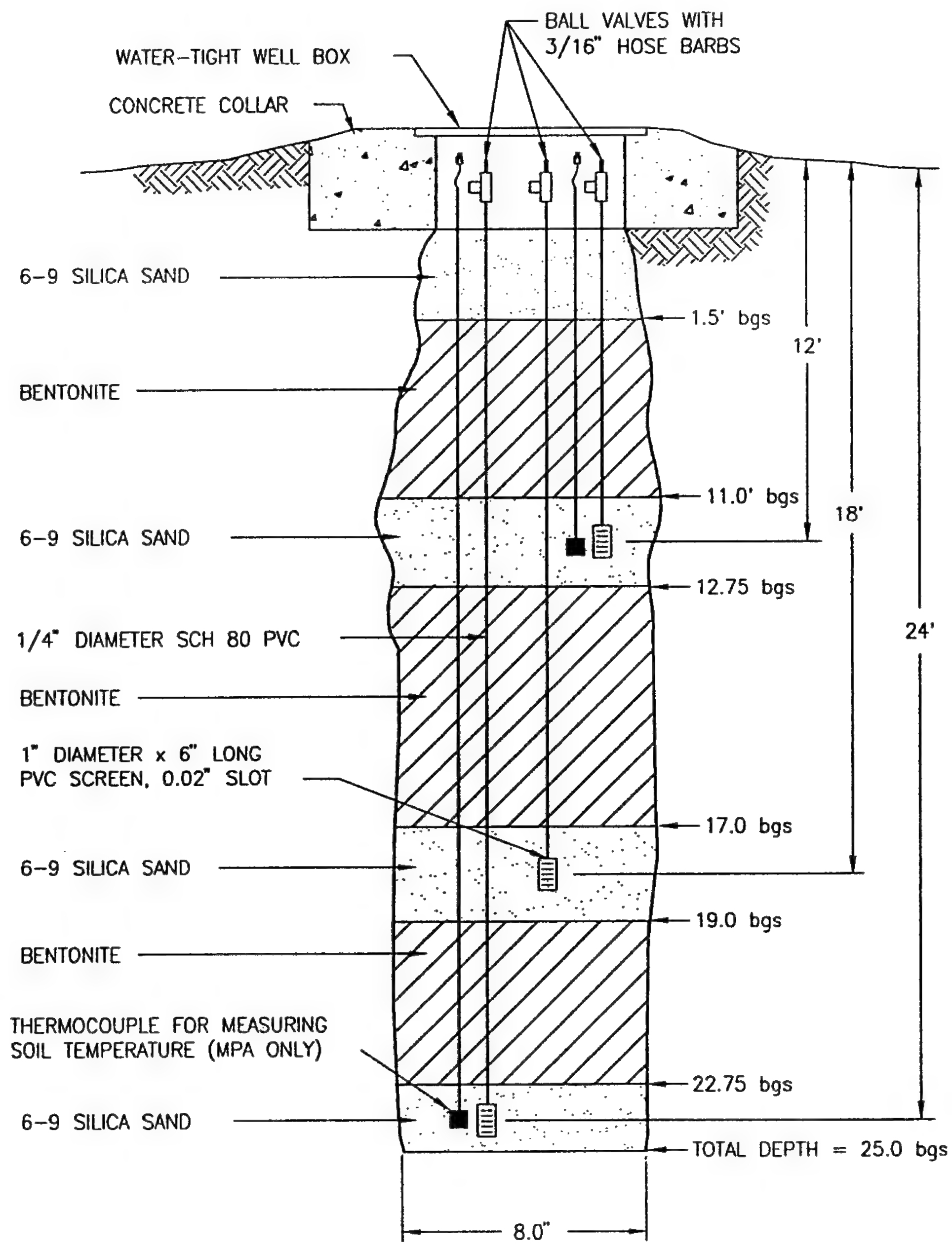

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FIGURE 1.4
AS-BUILT MONITORING POINT
CONSTRUCTION DETAIL
SITE B-2093

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

DETKE 3/11/94

volt, single-phase, 20-amp line power from a newly installed power outlet temporarily placed on the outer wall of building 2093. The configuration, instrumentation, and specifications for this temporary blower system are shown on Figure 1.5. The blower was originally turned on at site B-2093 on 17 January 1994, for air permeability testing and was continually operated at the site until 22 January 1994. Initially, only a flow rate of 9 cubic feet per minute (cfm) was permitted into the 20-foot screened length due to the tight formation. Each day the flow into the subsurface soils was slightly increased until the departure day (22 January 1994), when the flow into the ground had increased to 20 acfm. These flows were determined from the blower curves for the Roots 3 hp blower (based on inlet air at 14.7 psia and 68°F), and by measuring the bleed flow from the manual relief gate valve. The blower was dismantled from the VW on 22 January 1994, and the blower box (shed) was constructed over the 4-inch PVC stick up. A high-pressure, low-flow, rotary vane blower has been selected for use at the site and will be installed at the site in March 1994. After installation, ES engineers will provide an operation and maintenance (O&M) manual, including maintenance instructions, equipment specifications, and monitoring forms to base personnel.

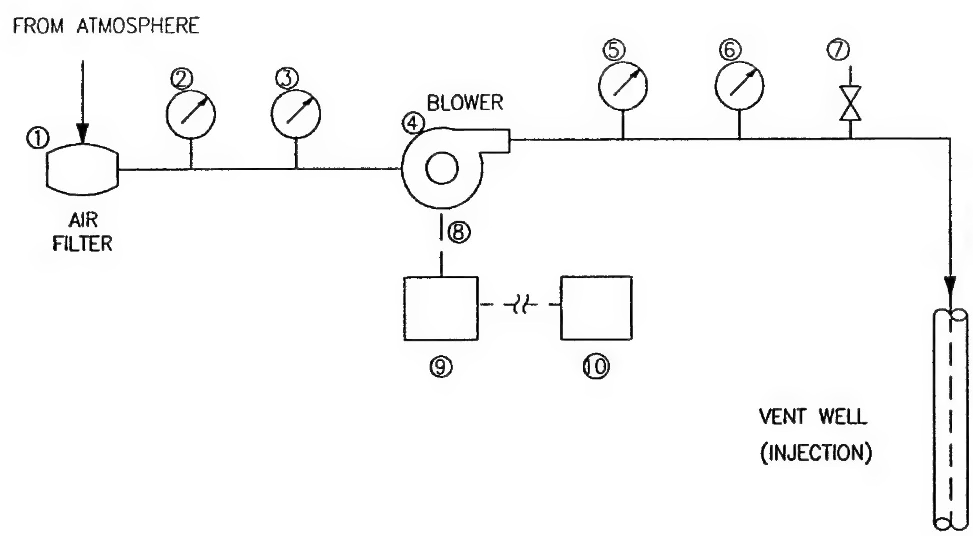
1.2 PILOT TEST SOIL AND SOIL GAS SAMPLING RESULTS

1.2.1 Sampling results

Soils at this site primarily consist of gray to brown clay with increasing silt content with depth. Although groundwater was not encountered during drilling, a static groundwater level of approximately 21.0 feet bgs was measured in the VW after construction on 12 January 1994. On 9 March 1994, the groundwater level had risen to about 5 feet bgs in the VW. More detailed hydrogeologic information regarding site B-2093 can be found in the hydrogeologic cross section (Figure 1.2) and the geologic boring logs (appendix A). Of note, the soil structure was very weak, causing the clay aggregates to be arranged more in a massive, rather than a porous blocky structure, resulting in little to no noticeable macro porosity in the vadose zone of the soil profile.

Hydrocarbon contamination at this site appears to extend from approximately 3 feet to at least 28 feet bgs (total depth drilled in VW). Contaminated soils were encountered in the VW and all three MPs drilled at the site. Contaminated soils were identified based on visual appearance, odor, and results of total hydrocarbon analyzer field screening for volatile organic compounds (VOCs). Contaminant concentrations generally increased with depth (Figure 1.2).

Soil samples for laboratory analysis were collected from 18-inch split-spoon samplers using a 2-inch-diameter brass liner for KE4 MPA12 and KE4 MPB18, and sample bottles for sample KE4 VW15. Soil samples were screened for VOCs using a hydrocarbon analyzer to determine the presence of contamination and to select soil samples for laboratory analysis. Soil samples for laboratory analysis were collected from MPA and MPB at a depth of 12.0 to 18.0 feet bgs, respectively, and from the VW at a depth of 15 feet bgs.



LEGEND

① INLET AIR FILTER
② VACUUM GUAGE
③ TEMPURATURE GAUGE (INLET FLOW)
④ BLOWER ROOTS® 3hp 22V-RAI
⑤ PRESSURE GUAGE
⑥ TEMPERATURE GUAGE (OUTLET FLOW)
⑦ MANUAL PRESSURE RELIEF (BLEED) VALVE – 1 1/2" GATE
⑧ ELECTRIC CORD CONNECTING BLOWER TO TRILOC OUTLET.
⑨ 208 V SINGLE PHASE/20 AMP OUTLET
⑩ BREAKER BOX – 30 AMP

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FIGURE 1.5
TRAILER MOUNTED
BLOWER SYSTEM
FOR AIR INJECTION
SITE B-2093

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

DETKE 3/11/94

Soil gas samples were collected from the completed VW and at 12.0 feet bgs from MPA and 18 feet bgs in MPB. TRPH samples did not indicate significant soil contamination, however SW8020 analysis for BTEX showed significant contamination. Low TRPH values are likely the result of volatilization from the soil sample during sample preparation. Soil gas samples were collected using 3-liter Tedlar® bags and vacuum chambers. Due to the tight formation, the soil gas samples collected at this site are likely diluted by atmospheric interferences. After the samples were collected with Tedlar bags, they were transferred to 1-liter SUMMA® canisters and shipped to the laboratory.

Soil samples were shipped via air express service to Pace Laboratories in Huntington Beach, California, for chemical and physical analysis. Soil samples were analyzed for total recoverable petroleum hydrocarbons (TRPH); benzene, toluene, ethyl benzene and xylenes (BTEX); iron; alkalinity; total Kjeldahl nitrogen (TKN); and several physical parameters. Soil gas samples were shipped via air express service to Air Toxics, Inc., in Folsom, California, for total volatile hydrocarbon (TVH) and BTEX analysis. The TVH analyses were referenced to JP-4 jet fuel. The results of these analyses are provided in Table 1.1. Chain-of-custody forms are provided in appendix B.

1.2.2 Exceptions to test protocol procedures

Procedures described in the protocol document (Hinchee et al., 1992) were used to complete the pilot test at site B-2093, with the following exceptions:

- The respiration test was not performed after determining that collecting representative soil gas samples from the MPs in the tight soils was not possible. A respiration test will be attempted after 6 months of air injection has hopefully increased soil porosity.
- There were no suitable locations identified by Kelly AFB to install a background MP in soils similar to those found throughout the screened intervals of the VW and MPs constructed at the site. Therefore, the data recovered from the background MP installed at site FC-2 was used as background data for site B-2093. The background MP at site FC-2 was installed in gravelly clay soils which are different to those found at site B-2093, and the background MP screens were set much shallower than the depths of the MP screens installed at site B-2093.

1.3 PILOT TEST RESULTS

1.3.1 Initial soil gas chemistry

Prior to initiating air injection, all MPs and the VW were purged, soil gas samples were collected, and initial oxygen, carbon dioxide, and TVH concentrations were measured using portable gas analyzers, as described in the technical protocol document (Hinchee et al., 1992). Table 1.2 summarizes the initial soil gas chemistry at site B-2093. It was not possible to collect soil gas samples representative of conditions present in the clay formation due to the weakly structured tight clays. A 2 minute purge of each MP and a 5 minute purge of the VW produced a negative

Table 1.1 Site B-2093
Soil and Soil Gas Analytical Results
Kelly AFB, Texas

Analyte (Units)[a/]	Sample Location-Depth (feet below ground surface)		
Soil Hydrocarbons	VW-15	MPA-12	MPB-18
TRPH (mg/kg)	ND [b/]	25.8	130
Benzene (mg/kg)	0.019	10	30
Toluene (mg/kg)	0.066	100	300
Ethylbenzene (mg/kg)	0.008	34	84
Xylenes (mg/kg)	0.064	170	430
Soil Gas Hydrocarbons	VW	MPA-12	MPB-18
TVH (ppmv)	7,600	4,800	16,000
Benzene (ppmv)	160	65	300
Toluene (ppmv)	170	99	700
Ethylbenzene (ppmv)	20	8.1	46
Xylenes (ppmv)	61	31	170
Soil Inorganics	VW-15	MPA-12	MPB-18
Iron (mg/kg)	14,000	14,000	14,100
Alkalinity (mg/kg as $CaCO_3$)	982	953	1,360
pH (units)	8.2	8.3	8.2
TKN (mg/kg)	330	340	270
Phosphates (mg/kg)	890	650	1,100
Soil Physical Parameters	VW-15	MPA-12	MPB-18
Moisture (% wt.)	19.2	19.5	17.4
Gravel (%)	0.0	0.0	0.0
Sand (%)	0.1	0.2	0.1
Silt (%)	49.7	54.5	56.6
Clay (%)	50.2	45.3	43.3
Soil Temperature (°F)	MPA-12	MPA-24	
(Measured on 14 Jan 94)	71.1°F	73.3°F	
Background TKN (mg/kg)	570		

a/ TRPH=total recoverable petroleum hydrocarbons; mg/kg=milligrams per kilogram; TVH=total volatile hydrocarbons; ppmv=parts per million, volume per volume; $CaCO_3$=calcium carbonate; TKN=total Kjeldahl nitrogen, °F=degrees Fahrenheit.

b/ ND=not detected.

pressure on the MP that prevented soil air sampling. A 90-second purge likely did not purge the entire air content from MPs, so atmospheric interference from air present in the casing caused diluted soil gas results. Even the diluted results indicate high levels of volatile hydrocarbons in the soil gas. The high hydrocarbon concentrations in the soil gas possibly indicate the volatilization of fuel from the pore space provided by the MP screen and casing at site B-2093. Although the measured oxygen levels suggest the soils may be aerobic, the gray coloring and abundant fuel vapors in the soils observed during drilling indicate that anaerobic conditions are likely throughout the contaminated vadose zone soils. Three MPs contained water in the screened interval. These were MPC18, MPC24, and MPB24. The background MP carbon dioxide level was 1.6 percent during the pilot test activities.

1.3.2 Air permeability

An air permeability test was conducted at site B-2093 according to protocol document procedures. Air was injected into the VW for approximately 5 days at a rate of approximately 9 to 20 acfm and an average pressure of approximately 10.0 pounds per square inch (psi). The final pressure response readings measured at each MP is listed in Table 1.3. Due to the inconsistent pressure responses observed over time the steady-state method of determining air permeability was selected using the final pressure response recorded. Using the steady-state method, a soil gas permeability value of 0.2 darcys was calculated for this site, which is typical for clay soils. The calculations, presented in appendix C, assume a maximum radius of influence of 15 feet at 18- and 24-feet bgs, and 9 feet at 12 feet bgs. A radius of pressure influence of at least 12 feet was observed at the 18- and 24-foot depths, and at least 6 feet of influence was observed at the 12-foot depth.

1.3.3 Oxygen influence

The depth and radius of oxygen influence in the subsurface resulting from air injection into the central VW during pilot testing is the primary design parameter for a full-scale bioventing systems. Optimization of full-scale and multiple VW system requires pilot testing to determine the volume of soil that can be oxygenated at a given flow rate and VW screen configuration.

Determination of oxygen influence was not accomplished due to the difficulty of soil gas sample collection from the MPs. Generally, the radius of pressure influence can be used to estimate the distance from the air injection of long-term oxygen transport, it is anticipated that the radius of influence exceeds 12 feet at depth of 18 feet and below, and will exceed 6 feet at the 12-foot depth at an injection pressure of at least 10 psi. Pressure response measurements and possible soil gas sampling during the extended pilot test at this site will better define the effective treatment radius. Continued operation of a high-pressure, rotary vane blower should improve long-term oxygen influence.

Table 1.3 Final Pressure Responses Readings at Site B-2093, Kelly AFB, Texas

Monitoring Point	Depth (Feet bgs)	Distance From Vent Well (Feet)	Measurement (In Inches of H_2O)
MPA	12	6.5	0.48
MPB	12	12.2	0.00
MPC	12	24.3	0.01
MPA	18	6.5	0.46
MPB	18	12.2	0.07
MPC	18	24.3	0.24
MPA	24	6.5	2.50
MPB	24	12.2	0.10
MPC	24	24.3	0.00

1.3.4 In situ respiration rates

In situ respiration testing was not performed at site B-2093 because air samples could not be collected from any of the VW or MPs. Air was injected into the VW and MP screens MPA-24, MPB-18, and MPC-12, for 25 hours at a rate of less than 1 acfm per screened interval to deliver oxygen to contaminated soils. At the end of the 25-hour period, air injection ceased, and sampling of the soil gas was again unsuccessfully attempted. The pumps are capable of injecting 1 acfm, but the tightness of the soils resulted in much less air being injected into each MP than 1 acfm.

Since it is not yet possible to measure respiration at the site, oxygen utilization or biodegradation rates could not be calculated. Based on the nutrient levels, adequate moisture, the quantity of hydrocarbons present in the soils and positive results at other Kelly AFB sites, a rapid rate of degradation would be anticipated in soils that are able to receive oxygen.

1.3.5 Potential air emissions

Soil concentrations of BTEX compounds detected were less than 30 mg/kg; however, the contaminated soils present at site B-2093 will continue to generate additional VOCs in the soil pore space (Table 1.1). Thus, the long-term potential for air emissions from full-scale bioventing operations at this site is moderate. Initial emissions should be minimal because of low air injection rates and because accumulated vapors will move slowly outward from the air injection point and will be biodegraded as they move horizontally through the soil. The large area of asphalt and concrete covering portions of the site will also encourage horizontal movements and increased biodegradation. During the air permeability test, air was injected at 9 to 20 acfm. Health and safety hydrocarbon-analyzer air monitoring of the breathing zone at the site did not indicate that hydrocarbon concentrations had increased above 1 part per million, volume per volume (ppmv) during the test, and no hydrocarbon odors were observed after 48 hours of continuous air injection.

1.4 RECOMMENDATIONS

Observations of fuel vapors and soil color during the initial bioventing tests at this site suggests that anaerobic conditions are very likely to be present in the contaminated soils, and that air injection should stimulate aerobic fuel biodegradation. ES recommends that air injection continue at this site to determine the long-term radius of oxygen influence and to see if air injection can increase permeability to the point that *in situ* respiration tests can be performed.

A blower has been recommended for installation at the site for continuous air injection. It is scheduled to be installed in March 1994. In September 1994, ES will return to the site to attempt to sample and analyze the soil gas and conduct a repeat respiration test. At a minimum, the blower condition will be inspected and pressure responses at the MPs will be documented. In March 1995, a final respiration test will be conducted, and soil and soil gas samples will be collected from the site to determine the degree of remediation achieved during the first year of *in situ* treatment.

Based on the results of the first year of pilot-scale bioventing, AFCEE will recommend one of three options:

1. Upgrade the pilot-scale system, if necessary, and continue operation of the bioventing system for full-scale remediation of the site. AFCEE can assist the base in obtaining regulatory approval for upgrading and continued operation.
2. If final soil sampling indicates significant contaminant removal has occurred, AFCEE may recommend additional sampling to confirm that cleanup criteria have been achieved.
3. If significant difficulties or poor results are encountered during bioventing at this site, AFCEE may recommend removal of the blower system and proper abandonment of the VW and MPs.

2.0 SITE D-10

2.1 Pilot Test Design and Construction

Installation of an air injection vent well (VW) and three vapor monitoring points (MPs) at site D-10 began on 6 January 1994, and was completed on 7 January 1994. Drilling services were provided by Jones Environmental Drilling, Inc., of San Antonio, Texas. Well installation and soil sampling were directed by Brian Vanderglas, the Engineering-Science, Inc. (ES) site manager, and Susan Roberts, the ES site geologist. The following sections describe the final design and installation of the bioventing system at this site.

One VW, three MPs (MPA, MPB, and MPC), and a blower unit were installed at site D-10. Figures 2.1 and 2.2, respectively, depict the locations of and hydrogeologic cross sections for the VW and MPs completed at site D-10. A background MP was not installed at site D-10 because there were no known areas of uncontaminated soil at the site accessible for drilling. Therefore, data from the

Table 1.2 Site B-2093
Initial Soil Gas Chemistry
Kelly AFB, Texas

MP	Depth (ft)	O_2 (%)	CO_2(%)	Field TVH (ppmv)	Lab TVH (ppmv)	TRPH (mg/kg)
VW	8-28	19.5	3.9	>11,600	7,600	ND[a]
A	12	18.5	0.25	6,000	NS[b]	25.8
B	12	18.0	0.10	11,200	NS	NS
C	12	18.8	0.4	9,600	NS	NS
A	18	NP[b]	NP	NP	NS	NS
B	18	19.5	0.4	15,200	16,000	130
C	18	NP	NP	NP	NS	NS
A	24	19.9	0.6	4,400	NS	NS
B	24	NP	NP	NP	NS	NS
C	24	NP	NP	NP	NS	NS
BG[d]	4	19.75	1.6	38	NS	NS

a/ ND = not detected
b/ NS = not sampled
c/ NP = not samples due to H_2O in monitoring point
d/ Background well at site B-2093
Note: Initial soil gas from readings measured on 12 January 1994; 1 minute purge for MPs, 2 minute purge for VW. Not able to completely purge MPs and VW, and sample since formation is so tight.

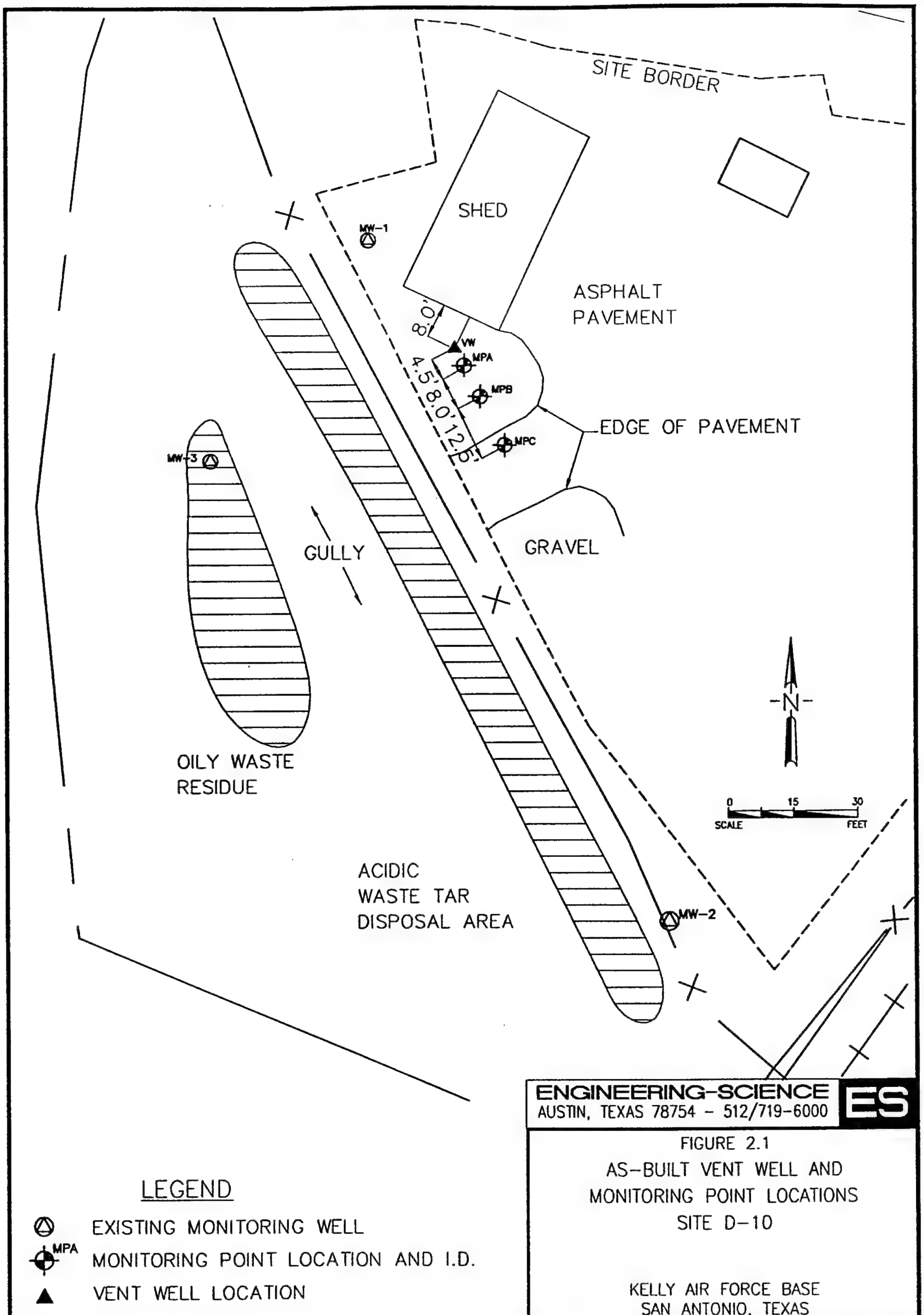

FIGURE 2.1
AS-BUILT VENT WELL AND MONITORING POINT LOCATIONS
SITE D-10

D10 3/11/94

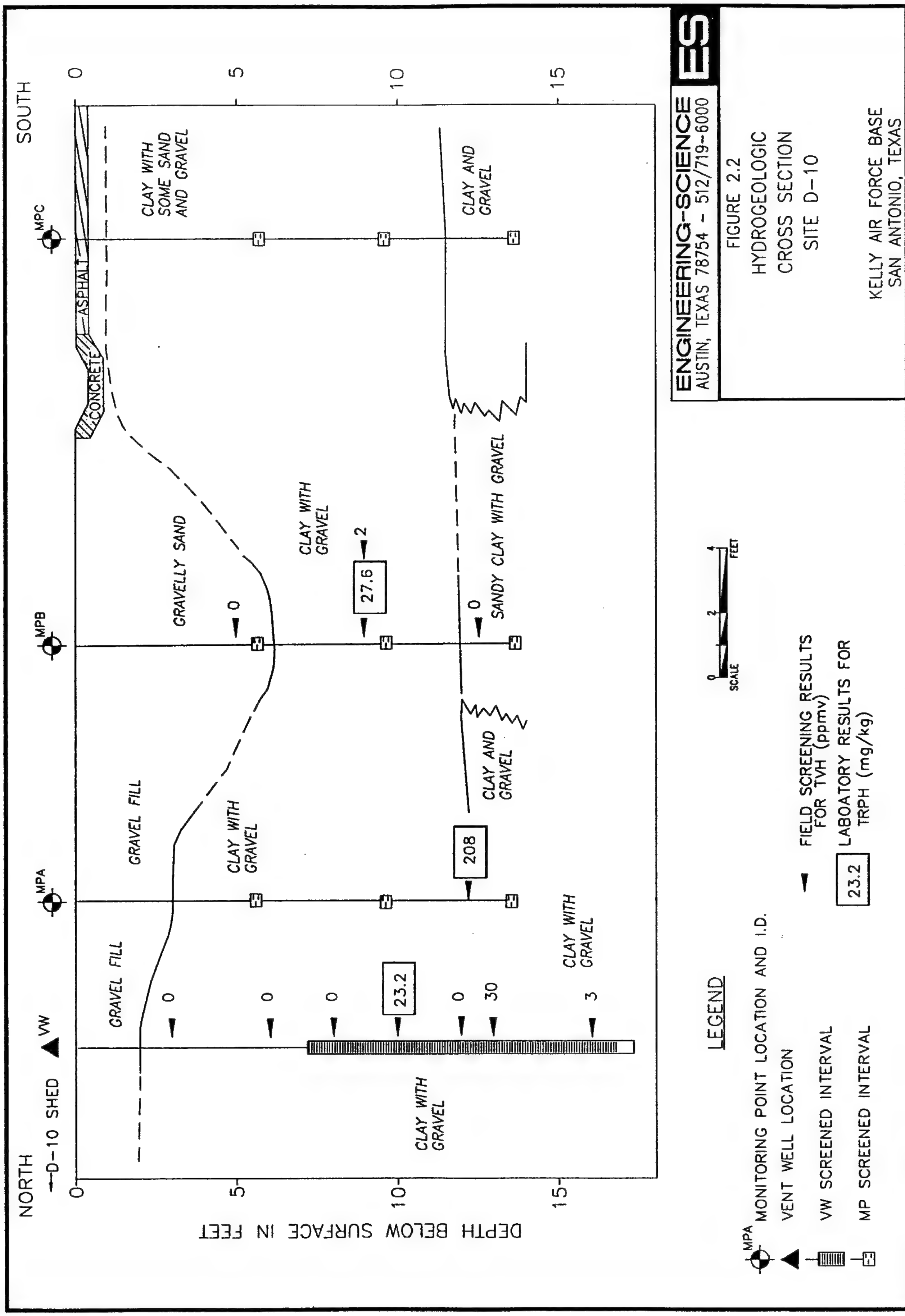
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FIGURE 2.2
HYDROGEOLOGIC
CROSS SECTION
SITE D-10
KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS
NORTH
SOUTH
D-10 SHED
VW
MPA
MPB
MPC
DEPTH BELOW SURFACE IN FEET
0
5
10
15
GRAVEL FILL
CLAY WITH GRAVEL
GRAVELLY SAND
CLAY AND GRAVEL
SANDY CLAY WITH GRAVEL
CLAY WITH SOME SAND AND GRAVEL
ASPHALT
CONCRETE
23.2
208
27.6
30
3
2
SCALE
FEET
LEGEND
MONITORING POINT LOCATION AND I.D.
VENT WELL LOCATION
VW SCREENED INTERVAL
MP SCREENED INTERVAL
FIELD SCREENING RESULTS FOR TVH (ppmv)
LABOATORY RESULTS FOR TRPH (mg/kg)
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background MP installed at site FC-2 from a separate pilot test performed at Kelly AFB was also applied to site D-10.

2.1.1 Air injection vent well

The air injection VW was installed following procedures described in the Air Force Center for Environmental Excellence (AFCEE) bioventing protocol document (Hinchee et al., 1992). Figure 2.3 shows construction details for the VW. The VW was installed in gravelly clay formation that contained hydrocarbon contamination at all sampling locations and depths. Groundwater was not encountered during drilling. The VW was constructed using 4-inch-diameter, schedule 40 polyvinyl chloride (PVC) casing, with 20 feet of 0.04-inch slotted PVC screen installed from approximately 7 to 17 feet bgs. The annular space between the well casing and borehole was filled with 6-9 silica sand from the bottom of the borehole to approximately 1.75 feet above the well screen. Approximately 5.4 feet of granular bentonite was placed above the sand in 6-inch lifts, with each lift being hydrated in place. On top of the bentonite layer, approximately 2.4 feet of concrete was placed and was finished flush with the existing asphalt surface. The well casing was cut off approximately 2 feet above the surface, and was temporarily fitted with a Fernco® coupler modified with a hose barb and ball valve for soil gas sampling. After soil gas testing, the casing was connected to the blower through a galvanized steel header using a rubber pipe coupler.

2.1.2 Monitoring points

At site D-10, the MP screens were installed at 5.5-, 9.5-, and 13.5-foot depths. The three MPs (MPA, MPB, and MPC) were constructed as shown in Figures 2.2 and 2.4. Each MP monitoring interval was constructed using a 6-inch section of 1-inch-diameter PVC well screen and a 0.25-inch-diameter schedule 80 PVC riser pipe extending to the ground surface. At the top of each riser, a ball valve and a $^3/_{16}$-inch hose barb were installed. The top of each MP was completed with a flush-mounted metal well protector set in a concrete base. Thermocouples were installed at the 5.5- and 13.5-foot depths at MPA to measure soil temperature. The existing groundwater monitoring well (MW) at the site could not be used as a soil gas MP because the screened interval was reportedly below the groundwater surface.

2.1.3 Blower unit

A 1.0-horsepower (hp) Gast® regenerative blower unit was used at site D-10 for both the initial testing and for the extended pilot test. The pilot test blower is energized by 220-volt, single-phase, 20-amp line power originating from a power pole next to the supply shed. A disconnect switch was set up on the outer wall of the shed near the blower. The configuration, instrumentation, and specifications for this blower system are shown on Figure 2.5. From the blower curve for model R4 blower series, the blower was transporting air at a flow rate of approximately 64 actual cubic feet per minute (acfm) for the extended pilot test, as of readings taken on 22 January 1994. After blower installation and startup, ES engineers

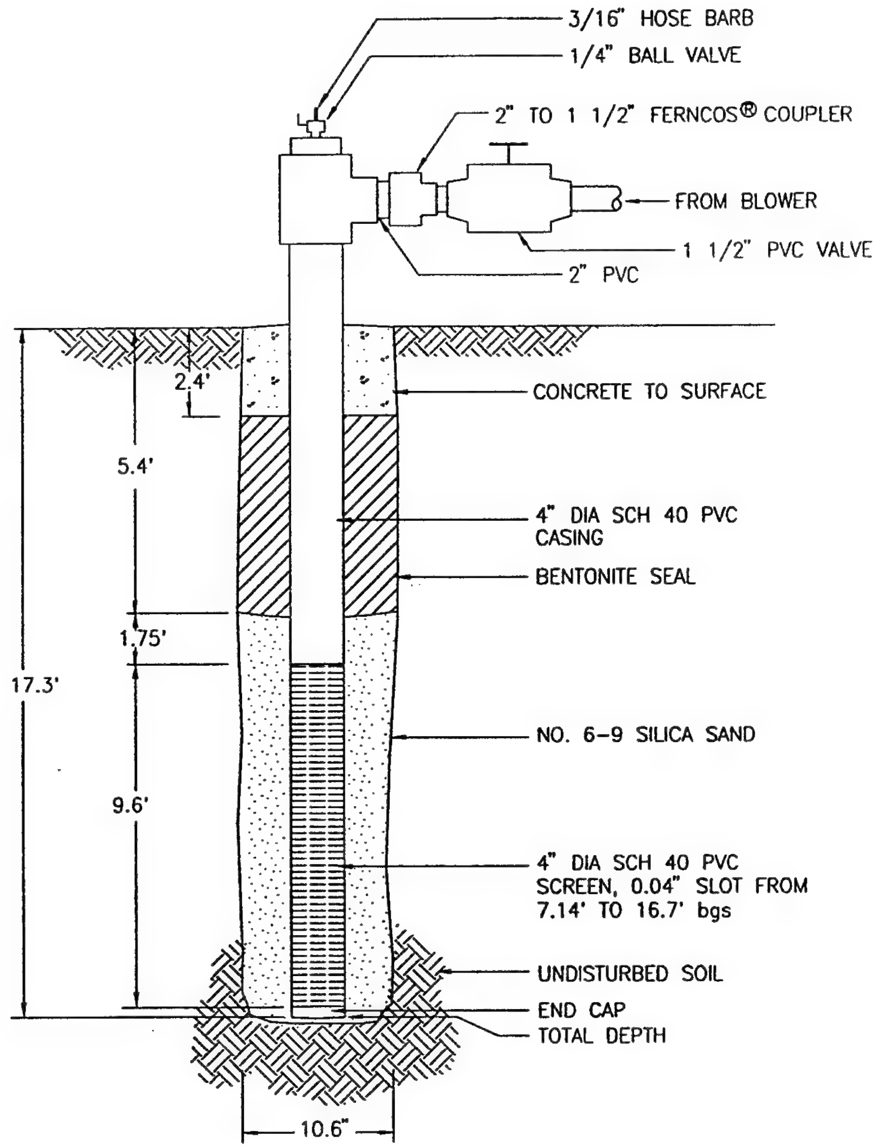

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FIGURE 2.3
AS-BUILT INJECTION VENT WELL CONSTRUCTION DETAIL
SITE D-10

KELLY AIR FOURCE BASE
SAN ANTOINIO, TEXAS

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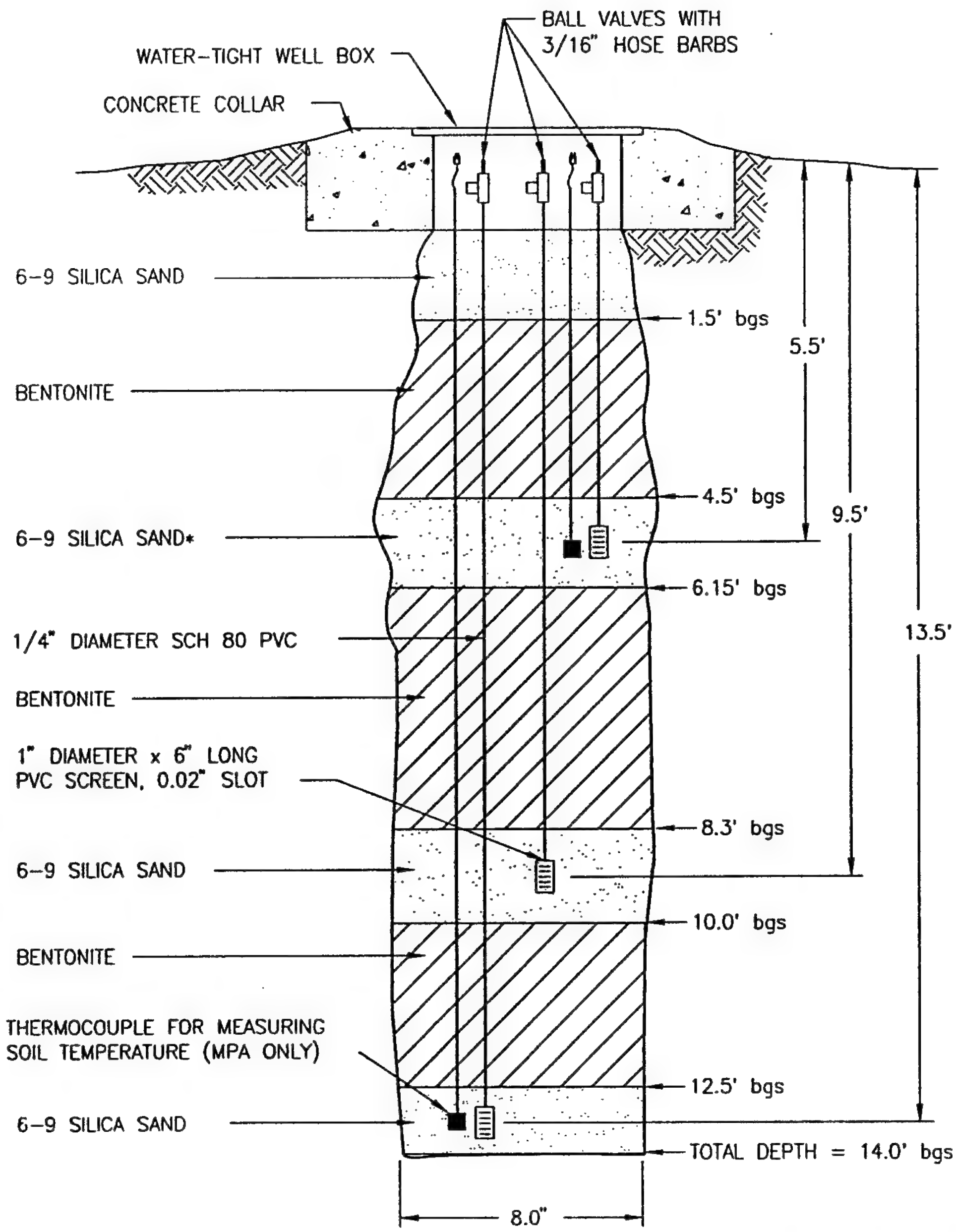

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FIGURE 2.4
AS-BUILT MONITORING POINT
CONSTRUCTION DETAIL
AT SITE D-10

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

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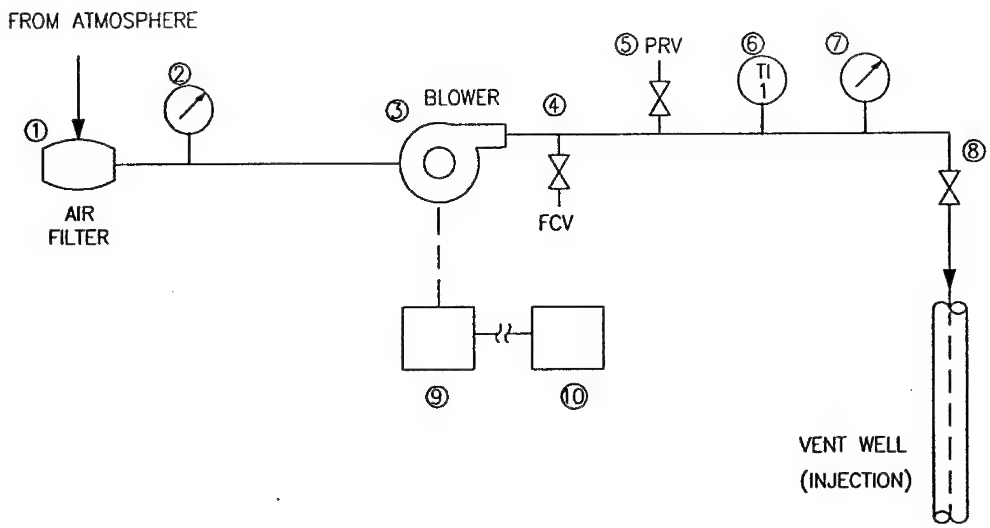

LEGEND

① INLET AIR FILTER – SOLBERG® AJ 134E
② VACUUM GUAGE (0–60 in. H20)
③ BLOWER – GAST® 1hp R4110–50
④ MANUAL PRESSURE RELIEF (BLEED) VALVE – 1 1/2 in. GATE
⑤ AUTOMATIC PRESSURE RELIEF VALVE, SET TO RELEASE AT 48 in. H20 PRESSURE.
⑥ TEMPURE GUAGE (0–250 °F)
⑦ PRESSURE GUAGE (0–100 in. H20)
⑧ FLOW CONTROL BALL VALVE – 1 1/2 in. PVC
⑨ DISCONNECT SWITCH 220 V SINGLE PHASE/20 AMP
⑩ BREAKER BOX, MOUNTED ON D–10 SHED

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FIGURE 2.5
AS–BUILT BLOWER SYSTEM
INSTRUMENTATION DIAGRAM
FOR AIR INJECTION
SITE D–10

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

DETD10 3/31/94

provided an operation and maintenance (O&M) manual, including maintenance instructions, equipment specifications, and monitoring forms to base personnel.

2.2 PILOT TEST SOIL AND SOIL GAS SAMPLING RESULTS

2.2.1 Sampling results

Soils at this site primarily consist of gravelly clay with some interbedded limestone gravel and silt. Groundwater was not encountered during drilling activities at the site. More detailed hydrogeologic information regarding site D-10 can be found in the hydrogeologic cross section (Figure 2.2) and the geologic boring logs (appendix A).

Hydrocarbon contamination at this site appears to extend from approximately 5 feet to at least 17 feet bgs (total depth drilled in VW). Contaminated soils were encountered in the VW and all three MPs drilled at the site, and the degree of contamination appeared to increase with depth. Contaminated soils were identified based on visual appearance, odor, and results of total hydrocarbon analyzer field screening for volatile organic compounds (VOCs).

Soil samples for laboratory analysis were collected from 18-inch split-spoon samplers using sample bottles for packing and shipping the soil samples. Soil samples were screened for VOCs using a hydrocarbon analyzer to determine the presence of contamination and to select soil samples for laboratory analysis. Soil samples for laboratory analysis were collected from MPA and MPB at a depth of 12.0 to 9.0 feet bgs, respectively, and from the VW at a depth of 10 feet bgs.

Soil gas samples were collected from the completed VW and at 13.5 feet bgs from MPA and MPC. Soil gas samples were collected using 3-liter Tedlar® bags and vacuum chambers. After the samples were collected with Tedlar bags, they were transferred to 1-liter SUMMA® canisters and shipped to the laboratory.

Soil samples were shipped via air express service to Pace Laboratories in Huntington Beach, California, for chemical and physical analysis. Soil samples were analyzed for total recoverable petroleum hydrocarbons (TRPH); benzene, toluene, ethyl benzene and xylenes (BTEX); iron; alkalinity; total Kjeldahl nitrogen (TKN); and several physical parameters. Soil gas samples were shipped via air express service to Air Toxics, Inc. in Folsom, California, for total volatile hydrocarbon (TVH) and BTEX analysis. The results of these analyses are provided in Table 2.1. Chain-of-custody forms and supporting data sheets are provided in appendix C.

2.2.2 Exceptions to test protocol procedures

Procedures described in the protocol document (Hinchee et al., 1992) were used to complete the pilot test at site D-10, with the following exception. Due to the reportedly widespread extent of contamination at site D-10, there were no suitable locations identified by Kelly AFB to install a background MP. Therefore, the data recovered from the background MP installed at site FC-2 was used as background data for site D-10. The background MP at site FC-2 was installed in gravelly clay

Table 2.1 Site D-10
Soil and Soil Gas Analytical Results
Kelly AFB, Texas

Analyte (Units)[a/]	Sample Location-Depth (feet below ground surface)		
Soil Hydrocarbons	VW-10	MPA-12	MPB-9
TRPH (mg/kg)	23.2	208	27.6
Benzene (mg/kg)	.0029	0.0017	ND[b/]
Toluene (mg/kg)	0.016	0.0077	0.0051
Ethylbenzene (mg/kg)	ND	ND	ND
Xylenes (mg/kg)	0.004	0.0011	ND
Soil Gas Hydrocarbons	VW	MPA-13.5	MPB-13.5
TVH (ppmv)	33	100	28
Benzene (ppmv)	ND	ND	ND
Toluene (ppmv)	0.79	0.35	0.038
Ethylbenzene (ppmv)	0.40	0.12	0.008
Xylenes (ppmv)	0.22	0.79	0.019
Soil Inorganics	VW-10	MPA-12	MPB-9
Iron (mg/kg)	11,290	15,400	13,200
Alkalinity (mg/kg as $CaCO_3$)	1,230	992	930
pH (units)	7.6	7.8	7.6
TKN (mg/kg)	420	800	700
Phosphates (mg/kg)	170	590	160
Soil Physical Parameters	VW-15	MPA-12	MPB-18
Moisture (% wt.)	23.4	19.9	24.1
Gravel (%)	6.9	56.0	9.5
Sand (%)	30.1	24.4	29.9
Silt (%)	32.4	9.6	27.7
Clay (%)	30.7	10.0	32.8
Soil Temperature (°F)	MPA-5.5	MPA-13.5	
Measured on 14 Jan 94	64.2 °F	70.6°F	
Background TKN (from FC-2)	570		

a/ TRPH = total recoverable petroleum hydrocarbons; mg/kg = milligrams per kilogram; TVH = total volatile hydrocarbons; ppmv = parts per million, volume per volume; $CaCO_3$ = calcium carbonate; TKN = total Kjeldahl nitrogen, °F = degrees Fahrenheit.

b/ ND = not detected.

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soils which are similar to those found at site D-10, and the background MP screens were set at approximately the same depths as the MP screens installed at site D-10.

2.3 PILOT TEST RESULTS

2.3.1 Initial soil gas chemistry

Prior to initiating air injection, all MPs and the VW were purged, soil gas samples were collected, and initial oxygen, carbon dioxide, and TVH concentrations were measured using portable gas analyzers, as described in the technical protocol document (Hinchee et al., 1992). Table 2.2 summarizes the initial soil gas chemistry at site D-10. The results indicate that biological fuel degradation has depleted the oxygen supply in the vadose zone soils. Four of the ten sampling points at site D-10 were under anaerobic conditions (all three 13.5-foot intervals and MPC 9.5), soil gas at two sampling points contained oxygen at low levels ranging from 0.5 percent to 2.0 percent (MPB 9.5 and VW), and soil gas at the remaining four points exhibited slightly aerobic conditions with oxygen levels ranging from 6.0 percent to 9.2 percent. In contrast, the background MP, installed in uncontaminated soil at site FC-2, contained oxygen at levels of 19.7 percent. Carbon dioxide was present at elevated concentrations, ranging from 1.2 to 11.5 percent, in all initial soil gas samples collected at site D-10. The background MP carbon dioxide levels were 1.6 percent.

2.3.2 Air permeability

An air permeability test was conducted at site D-10 according to protocol document procedures. Air was injected into the VW for approximately 1 hour at a rate of approximately 25 acfm and an average pressure of approximately 50 inches of water. The final pressure response readings measured at each MP is listed in Table 2.3. The pressure measured at all MPs achieved steady-state conditions within 7 minutes. Due to the rapid response and relatively short time to achieve steady-state conditions, the steady-state method of determining soil gas permeability was selected. As discussed in the technical protocol document (Hinchee et al., 1992), the dynamic method of determining soil gas permeability that is coded in the HyperVentilate® model is not appropriate for soils which reach steady-state in less than approximately 10 minutes. Using the steady-state method, a soil gas permeability value of 6.9 to 7.2 darcys was calculated for this site. A radius of pressure influence of at least 25 feet was observed at all depths. The calculation sheets are included in appendix C.

2.3.3 Oxygen influence

The depth and radius of oxygen influence in the subsurface resulting from air injection into the central VW during pilot testing is the primary design parameter for full-scale bioventing systems. Optimization of full-scale and multiple VW systems requires pilot testing to determine the volume of soil that can be oxygenated at a given flow rate of VW screen configuration.

Table 2.2 Site D-10
Initial Soil Gas Chemistry
Kelly AFB, Texas

MP	Depth (ft)	O_2 (%)	CO_2(%)	Field TVH (ppmv)	Lab TVH (ppmv)	TRPH (mg/kg)
VW	7-17	2.0	11.5	260	33	23.2
A	5.5	8.5	7.5	89	NS [a]	NS
B	5.5	9.2	7.0	790	NS	NS
C	5.5	8.0	6.7	74	NS	NS
A	9.5	6.0	7.5	125	NS	NS
B	9.5	0.5	1.2	105	NS	27.6
C	9.5	0.0	8.5	110	NS	NS
A	13.5	0.0	9.5	600	100	208
B	13.5	0.0	10.5	930	NS	NS
C	13.5	0.0	8.0	340	28	NS
BG [b]	4	19.7	1.6	38	NS	NS

a/ NS = not sampled
b/ Background well at site FC-2
Note: Initial soil gas from readings measured on 17 January 1994; 1 minute purge for MPs, 5 minute purge for VW.

Table 2.3 Site D-10
Pressure Response During the Air Permeability Test
Kelly AFB, Texas

	Pressure Response In MP (Inches of Water)								
	MPA			MPB			MPC		
Depth (ft)	5.5	9.5	13.5	5.5	9.5	13.5	5.5	9.5	13.5
Elapsed Time (in minutes)									
0.5	0.4	0.65	1.10	0.29	0.31	1.6	>0.25	>.25	0.6
1.0	0.4	0.65	1.10	0.31	0.32	1.7	-- [a]	--	--
1.5	0.4	0.65	1.10	--	--	--	--	--	--
2.0	0.4	0.65	1.10	0.31	0.34	1.8	--	--	0.65
2.5	0.4	0.65	1.10	--	--	--	>0.25	--	--
3.0	0.4	0.65	1.10	0.33	0.34	1.85	>0.25	0.46	0.65
3.5	0.4	0.65	1.10	0.32	0.33	1.8	--	--	0.7
7.0	0.4	0.65	1.10	0.33	0.34	1.8	0.29	0.46	0.65
10.0	0.4	0.65	1.10	--	--	--	--	--	--
60.0	0.4	0.65	1.10	0.33	0.34	1.8	0.29	0.46	0.65

a/ -- Denotes no reading taken at this time.

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Table 2.4 describes the change in soil gas oxygen levels that occurred during a 20-hour air injection test at the site. This air injection period at 25 to 64 acfm produced significant changes in soil gas oxygen levels at a distance of at least 25 feet from the central VW at all three monitored depth intervals. Significant increases in the oxygen concentration were measured at each MP interval. Based on measured pressure response, which is an indicator of long-term oxygen transport, it is anticipated that the radius of influence for a long-term bioventing system at this site will easily exceed 30 feet at all depths. Figure 2.6 depicts steady-state pressure response versus distance at an average of 25 acfm.

2.3.4 In situ respiration rates

In situ respiration testing was performed at site D-10 according to protocol document procedures. Air was injected into the VW and MP screens MPA-13.5, MPB-13.5, MPB-9.5, and MPC-13.5 for 16 hours at a rate of less than 1 acfm per screened MP interval to deliver oxygen to contaminated soils. At the end of the 19-hour period, air injection ceased, and changes in soil gas composition were monitored over time. Oxygen, TVH, and carbon dioxide were measured over a period of 72 hours following the air injection period. The observed rates of oxygen utilization were then used to estimate the aerobic fuel degradation rates at site D-10. Figures 2.7 through 2.11 present the results in *situ* respiration testing at the site, and Table 2.5 provides a summary of the observed oxygen utilization rates.

A 2- to 3-percent mixture of helium in air was injected into the MP screened intervals during the 19-hour air injection period. The loss of helium was also measured during the 72-hour respiration testing. Because helium is a conservative, inert gas, the change in helium concentrations over time can be useful in determining if oxygen diffusion is responsible for a portion of the oxygen lost from each MP. Figures 2.7 through 2.11 compare oxygen utilization and helium retention at the measuring points. Helium concentrations remained relatively constant in four of the MPs for the duration of the test, while oxygen levels steadily dropped. Helium concentrations slowly, but steadily decreased in MPB 9.5 from 2.9 percent 1 hour after stopping air injection, to 0.95 percent 72 hours later. Because the observed helium loss was significantly less than oxygen loss at this point, and because helium will diffuse approximately three times faster than oxygen, the measured oxygen loss at this point, and the four other MPs, can be primarily attributed to bacterial respiration rather than diffusion or faulty MP construction.

At site D-10, an estimated 1,200 - 20,450 milligrams (mg) of fuel per kilogram (kg) of soil can be degraded each year. This value is based on the range of the fuel consumption rates calculated for every point at which a respiration test was conducted. The point-specific fuel consumption rates were calculated using observed oxygen utilization rates, estimated air-filled porosities, and a conservative ratio of 3.5 mg of oxygen consumed for every 1 mg of fuel biodegraded. Oxygen loss was rapid and linear at every sampling point during approximately the initial 430 minutes of the *in situ* respiration test. The oxygen utilization rates observed at site D-10 ranged from .0034 percent per minute (%/min) to .049 %/min (Table 2.5), demonstrating that hydrocarbon biodegradation is relatively uniform

Table 2.4 Influence of Air Injection at VW1
on Monitoring Point Oxygen Levels, Site D-10
Kelly AFB, Texas

MP	Distance From VW (Feet)	Depth (Feet)	Initial Oxygen	Final Oxygen (%)[a]
A	4.5	5.5	8.5	20.8
A	4.5	9.5	6.0	20.8
A	4.5	13.5	0.0 [b]	20.0
B	12.5	5.5	9.25	20.8
B	12.5	9.5	11.75 [b]	18.5
B	12.5	13.5	3.0 [b]	20.8
C	25.0	5.5	8.0	17.0
C	25.0	9.5	0.0	19.5
C	25.0	13.5	0.5 [b]	20.8

a/ Duration of air injection = 20 hours.
b/ Final 72-hour reading from respiration test, prior to air injection/permeability test.

Table 2.5 Site D-10
Oxygen Utilization Rates
Dyess AFB, Texas

MP	O_2 Loss [a] (%)	Test Duration (Hour)	O_2 Utilization [a] Rate (%/minutes)
VW	20.0	4,379	0.014
MPA-13.5	19.25	527	0.049
MPB-9.5	8.5	4,375	0.0034
MPB-13.5	17.0	4,376	0.0096
MPB-13.5	19.3	4,373	0.018

a/ Values based on linear regression (Figures 2.6 through 2.10).

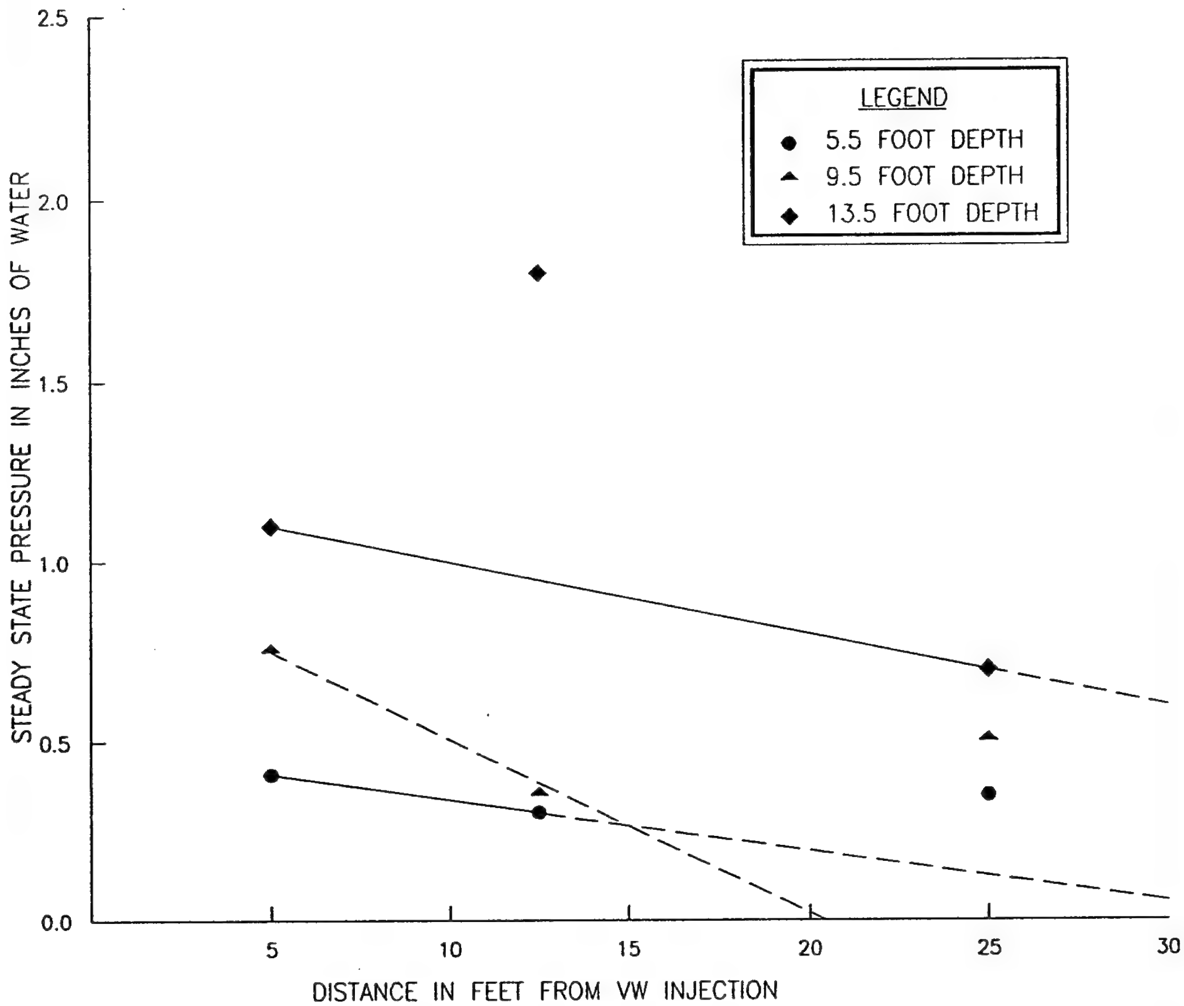

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FIGURE 2.6
RADIUS OF INFLUENCE
PRESSURE vs. DISTANCE
DETERMINATION
SITE D-10

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

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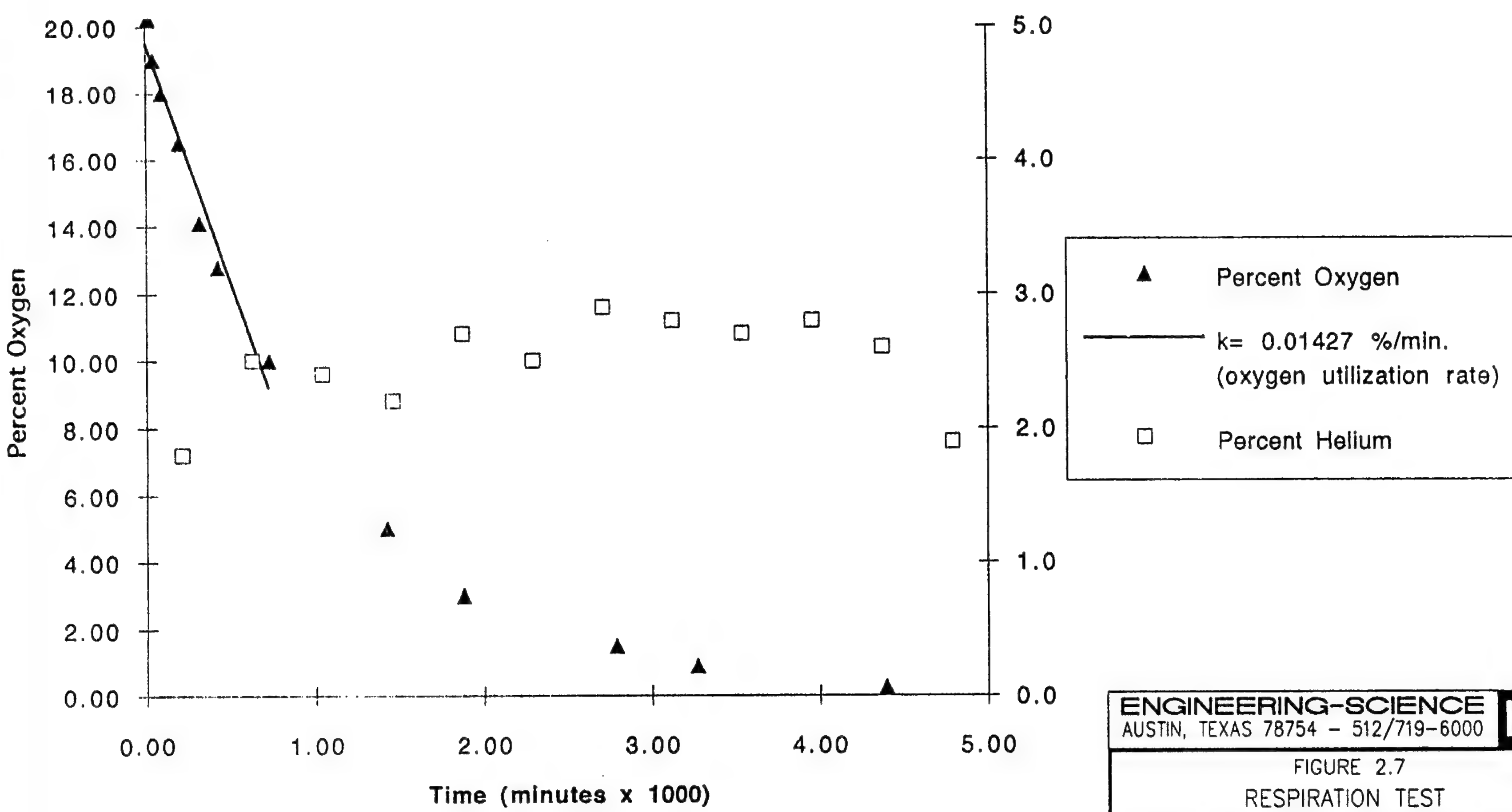

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FIGURE 2.7
RESPIRATION TEST
OXYGEN AND HELIUM CONCENTRATIONS
SITE D-10, VW

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

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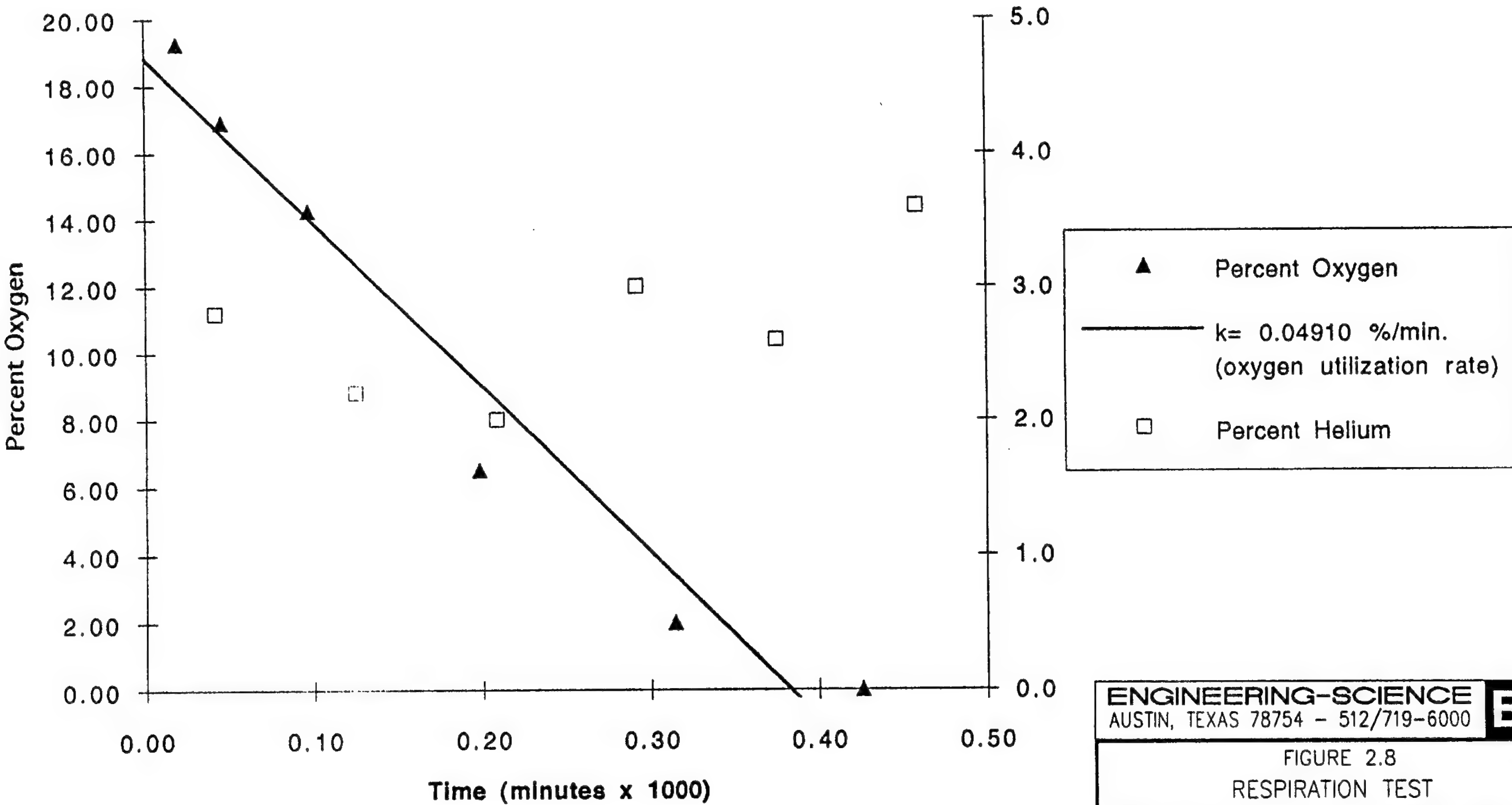

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FIGURE 2.8
RESPIRATION TEST
OXYGEN AND HELIUM CONCENTRATIONS
SITE D-10, MPA-13.5

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

RTSTD10 3/11/94

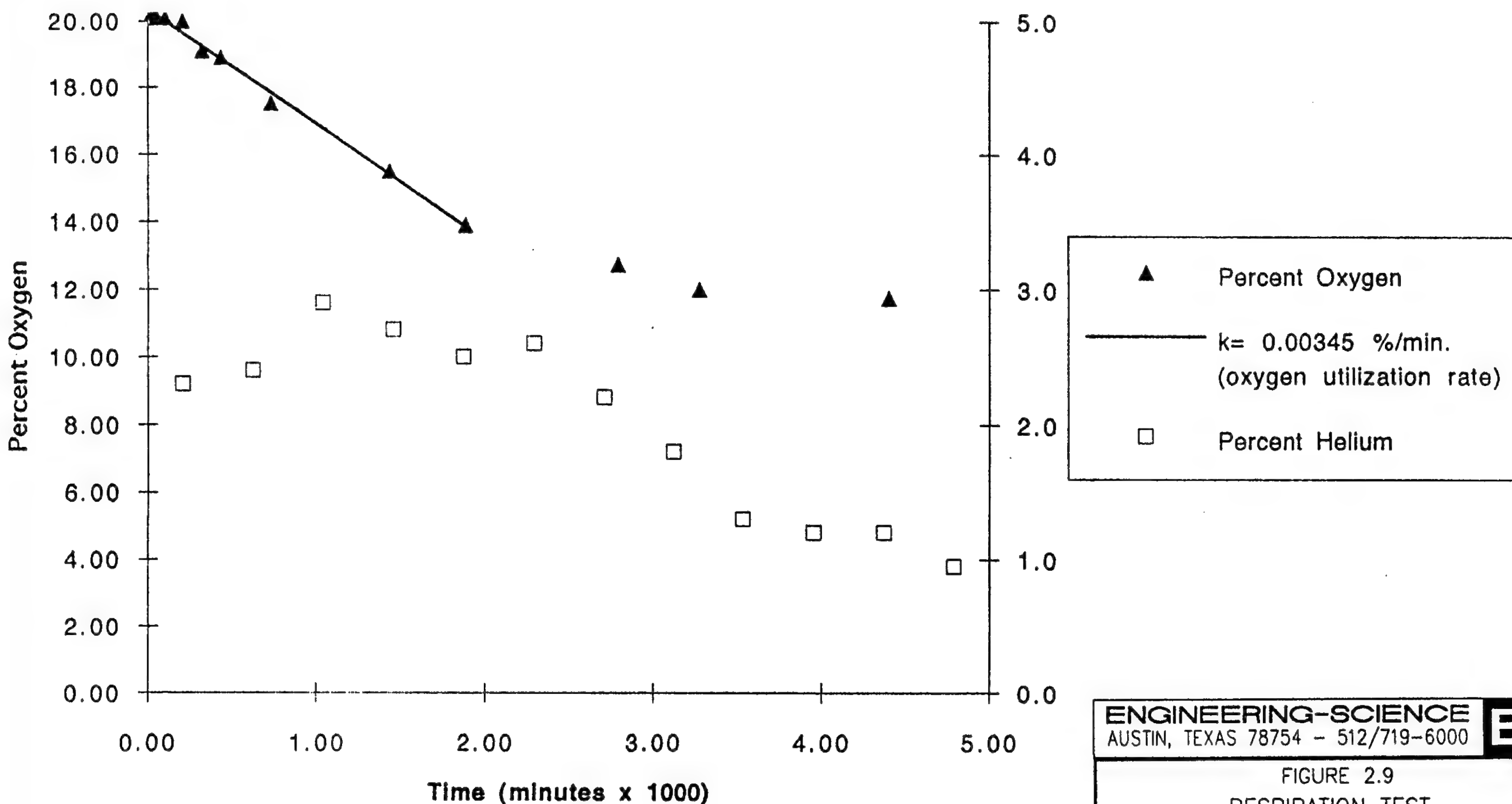

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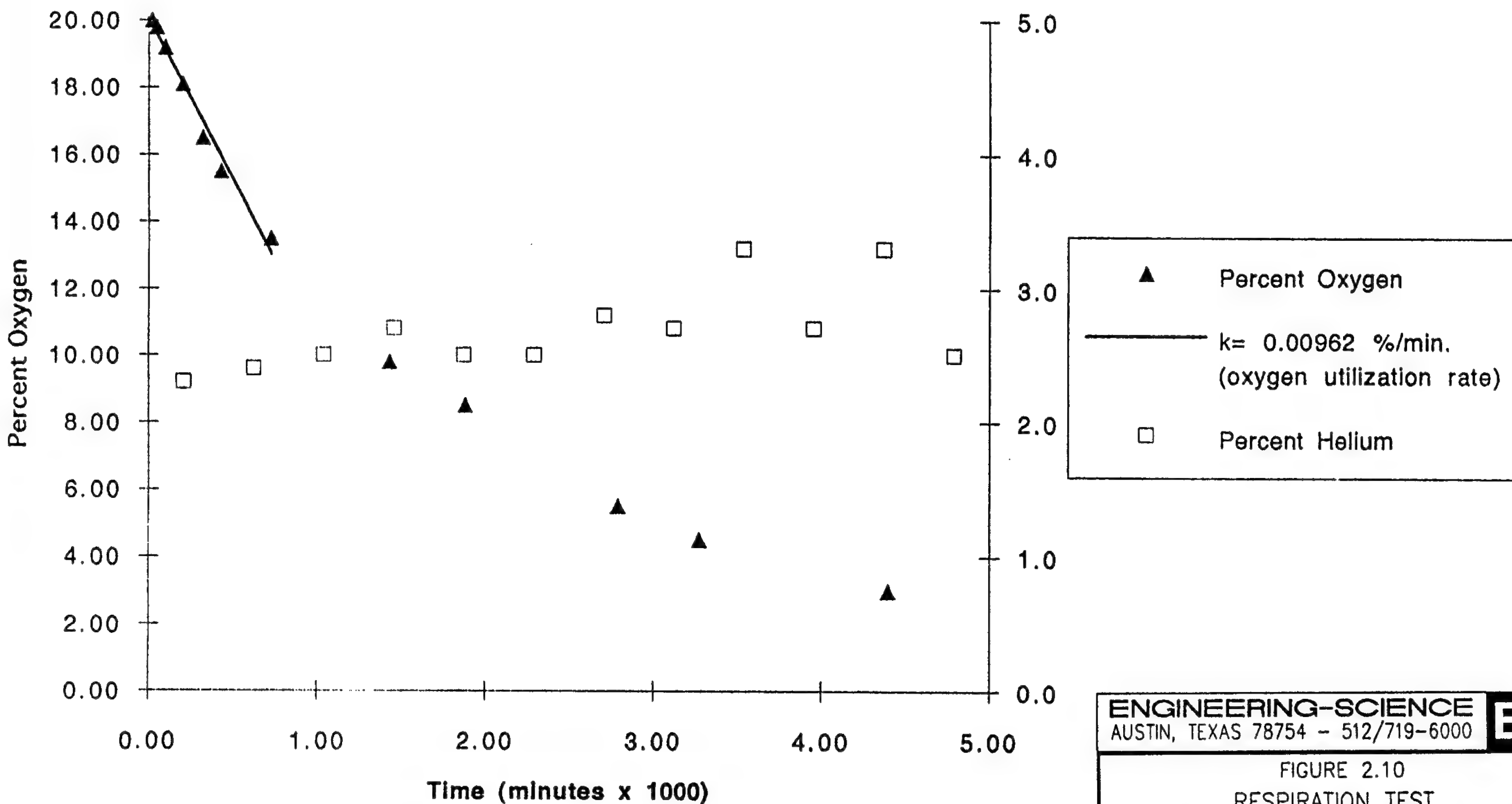
FIGURE 2.9
RESPIRATION TEST
OXYGEN AND HELIUM CONCENTRATIONS
SITE D-10, MPB-9.5

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

RTSTD10 3/11/94

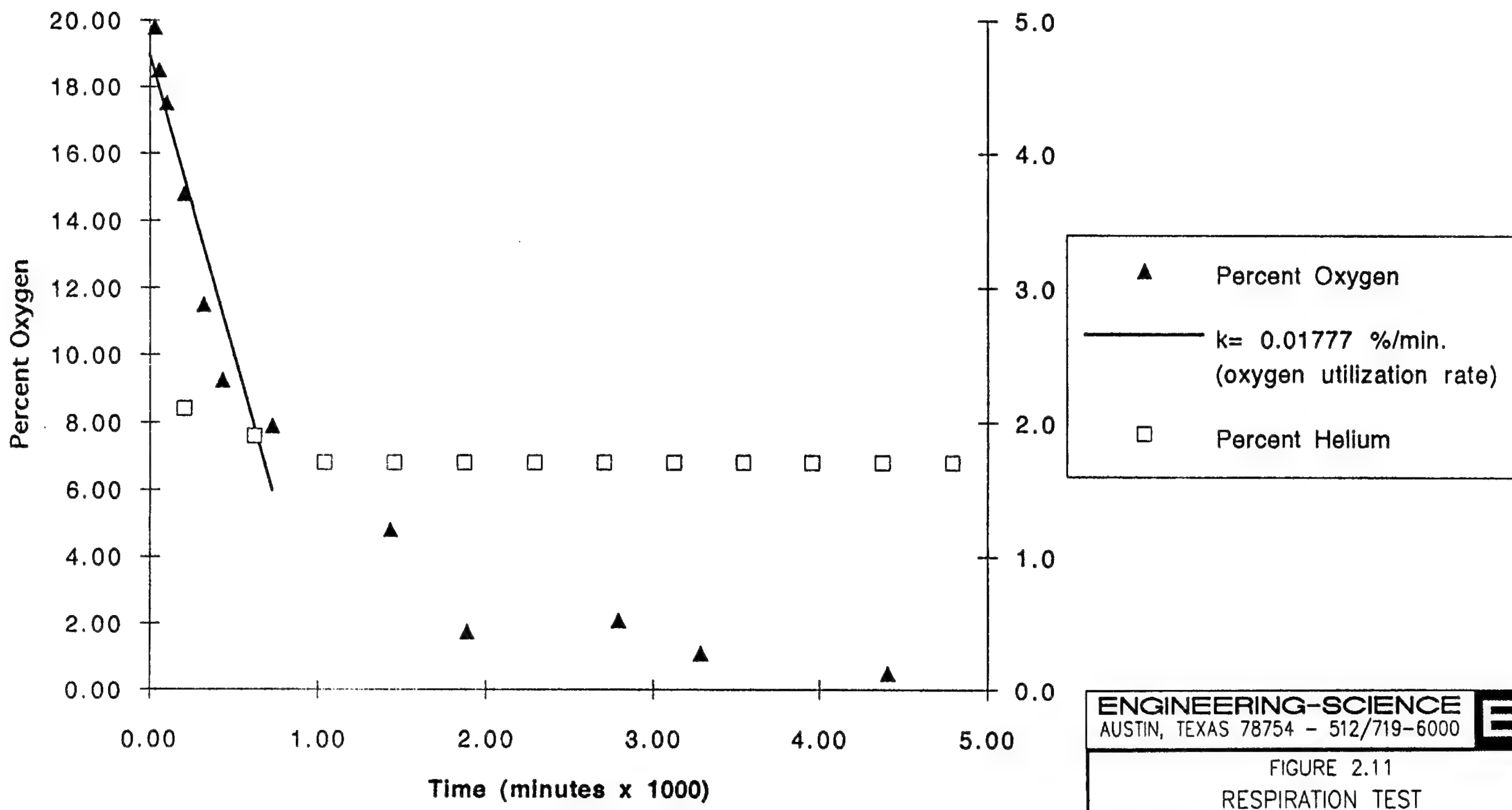


ENGINEERING-SCIENCE
AUSTIN, TEXAS 78754 - 512/719-6000

FIGURE 2.10
RESPIRATION TEST
OXYGEN AND HELIUM CONCENTRATIONS
SITE D-10, MPB-13.5

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

RTSTD10 3/11/94



ENGINEERING-SCIENCE
AUSTIN, TEXAS 78754 - 512/719-6000

FIGURE 2.11
RESPIRATION TEST
OXYGEN AND HELIUM CONCENTRATIONS
SITE D-10, MPC-13.5

KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

RTSTD10 3/11/94

through the pilot test area. The air-filled porosities calculated for each sampling point ranged from 0.17 to 0.20 liter of air per kilogram of soil.

2.3.5 Potential air emissions

Soil concentrations of BTEX compounds detected were less than 1 mg/kg. Thus, the long-term potential for air emissions from full-scale bioventing operations at this site is very low. Initial emissions should be minimal because accumulated vapors will move slowly outward from the air injection point and will be biodegraded as they move horizontally through the soil. During the air permeability test, air was injected at 24 to 64 acfm. Health and safety hydrocarbon-analyzer air monitoring of the breathing zone at the site did not indicate that hydrocarbon concentrations had increased above 1 part per million, volume per volume (ppmv) during the test, and no hydrocarbon odors were observed after 20 hours of continuous air injection.

2.4 RECOMMENDATIONS

Initial bioventing tests at this site indicate that oxygen had been depleted in the contaminated soils, and that air injection is an effective method of stimulating aerobic fuel biodegradation. Engineering-Science has recommended that air injection continue at this site to determine the long-term radius of oxygen influence and the effect of time, available nutrients, and changing temperatures on fuel biodegradation rates.

A 1-horsepower regenerative blower has been installed at the site for continuous air injection. In July 1994, ES will return to the site to sample and analyze the soil gas and conduct a repeat respiration test. In January 1995, a final respiration test will be conducted, and soil and soil gas samples will be collected from the site to determine the degree of remediation achieved during the first year of *in situ* treatment.

Based on the results of the first year of pilot-scale bioventing, AFCEE will recommend one of three options:

1. Upgrade the pilot-scale system, if necessary, and continue operation of the bioventing system for full-scale remediation of the site. AFCEE can assist the base in obtaining regulatory approval for upgrading and continued operation.
2. If final soil sampling indicates significant contaminant removal has occurred, AFCEE may recommend additional sampling to confirm that cleanup criteria have been achieved.
3. If significant difficulties or poor results are encountered during bioventing at this site, AFCEE may recommend removal of the blower system and proper abandonment of the VW and MPs.

Appendix A

Geologic Boring Logs

GEOLOGIC BORING LOG

BORING NO.:	VW-1	CONTRACTOR:	JEDI	DATE SPUD:	01/04/94
CLIENT:	AFCEE / Kelly AFB	RIG TYPE:	Mobile B63	DATE CMPL.:	01/07/94
JOB NO.:	722450.19040	DRLG METHOD:	HSA	ELEVATION:	
LOCATION:	2093 Kelly AFB	BORING DIA.:	10 3/4"	TEMP.:	~35 °F
GEOLOGIST:	S. Roberts	DRLG FLUID:	None	WEATHER:	Windy, mostly cloudy

COMMENTS:

Elev. (ft.)	Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1			0-0.5: asphalt + base					gasoline odors
			CL	0.5-~~SAA~~ CLAY some sand & gravel, pale yellow					
				(2.5Y 7/3), dry, NP, ↑ sand & silt @ 3'					
				4-6': CLAY trace silt, green (not on Munsell)	1	4-6	G	4-6	Field screen = 26 ppm
	5			mottled w/ lt olive brown (2.5Y 5/4) stiff, white chalk @ 4.2, 4.4, 5					hdsp = 2500 ppm
				1 in brown @ 5.8-6, dry to sl. moist					
				6-8': SAA, color change to lt. yellow br (2.5Y 6/4)					Field = 35 ppm
				mottled w/ light gray (5Y 6/1), 1" chalk @ 7.1', trace					
				chert gravel, dry, plastic					
	10			8-10: SAA, v stiff lt. olive brown (2.5Y 5/6) mottled	1	8-10	G	8-10	Field = 36 ppm, hdsp = 400
				w/ lt gray (5Y 7/2), no chalk or gravel	1	8-12	G		
				10-12: SAA small cracks (<1 mm) in clay, 1" chalk @ 11'	~~1~~	~~8-12~~	~~G~~	10-12	Field = 400 ppm, hdsp > 5000 ppm
				12-14: CL, some silt, olive yellow (5Y 6/6), mottled w/					Field = 2800 ppm,
				green from 12.5-14', sl. hydrocarbon	1	12-14	G	12-14	hdsp = ~~500 ppm~~ 1700 ppm
	15			14-15': SAA - no silt	1	15' KE4	D	15-16'	Field = 1000 ppm hdsp = >5000 ppm
									only sample kept.
				16-18': SAA - olive yellow (2.5Y 6/6)	1	16-18	G		Field = 1000 ppm, hdsp = 1500
				18-20': SAA, some black mottling @ 19.5' (Mn?)	1	18-20	G		Field = 350 ppm, hdsp = 480 ppm
	20								
				20-22': 20-20.4' - CL some sand & gravel, olive yellow	1	20-22	G		hdsp = 3000 ppm
				(2.5Y 6/?) dry, b... pebble, strong brown					
				(7.5YR 5/6), 20.4-22': CL, tr silt, yellow (2.5Y 7/6),					
				dry, mottled w/ green, sl. plastic	1	22-24	G		Field = 40 ppm, hdsp = 200
	25			22-24: SAA, tr sand, 24-26': CL some silt, tr sand,					
				to 25.5', v fn sand	1	24-26	G		hdsp = 300 ppm
				26-28': CL some sand & silt, lt yell. br (2.5Y 6/4)					Field = 150 ppm, } dup
				mottled w/ pale olive (5Y 6/3), dry, NP, v fn sand	1	26-28	G		hdsp = 350 ppm } sample
				TD = 28' BGS					
	30								

sl - slight	v - very	f - fine	**SAMPLE TYPE**
tr - trace	lt - light	m - medium	D - DRIVE
sm - some	dk - dark	c - coarse	C - CORE
& - and	bf - buff	BH - Bore Hole	G - GRAB
@ - at	brn - brown	SAA - Same As Above	
w - with	blk - black		

C Core recovery

Core lost

Water level drilled

GEOLOGIC BORING LOG

BORING NO.	MPA	CONTRACTOR:	JEDI	DATE SPUD:	01/08/94 0815
CLIENT:	AFCEE / Kelly AFB	RIG TYPE:	Mobile B-63	DATE CMPL:	01/08/94 0935
JOB NO.:	722407.19040	DRLG METHOD:	HSA	ELEVATION:	
LOCATION:	2093 Kelly AFB	BORING DIA.:	8"	TEMP.:	~30°F
GEOLOGIST:	J. Roberts	DRLG FLUID	None	WEATHER:	Clear, slight breeze
COMMENTS:					

Elev. (ft.)	Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1			0-0.4' : Asphalt + base					
			CL	0.4-5' cuttings are CL, little gravel,					
				yel-brown					
	5								
				5-7: CL, some silt, olive yellow (2.5Y 6/6),	1	5.5-7	G	Field Screen = 74 ppm	
				stiff, dry, wh. chert @ 6', roots, mottled w/					Hasp > 5000 ppm
				greenish gray (5Y 6/1) & sl. black					Didn't keep sample.
	10								
				SAA	1	11-13 KE 4 MPA 11'	C	11-13	Hasp = 1500 ppm
	15								
				SAA, ↑ in gray color, roots @ 16.8' & microcracks	1	15.5-17	G		Field > 5000 ppm
									Hasp > 5000 ppm
									Didn't keep sample.
	20								
				20-22: SAA, yellow mottled w/ gray, no roots or chert	1	20-22	G		Field = 1000 ppm
									Hasp = 1500 ppm
									Didn't keep sample
	25								
				TD = 25' BGS					
	30								

sl – slight
tr – trace
sm – some
& – and
@ – at
w – with

v – very
lt – light
dk – dark
bf – buff
brn – brown
blk – black

f – fine
m – medium
c – coarse
BH – Bore Hole
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB

C Core recovery
Core lost
Water level drilled

GEOLOGIC BORING LOG

BORING NO.	MPB	CONTRACTOR:	JEDI	DATE SPUD:	01/08/94 1400
CLIENT:	AFCEE / Kelly AFB	RIG TYPE:	Mobile B-63	DATE CMPL:	01/08/94 1500
JOB NO.:	722408.19040	DRLG METHOD:	HSA	ELEVATION:	
LOCATION:	2093 Kelly AFB	BORING DIA.:	8"	TEMP.:	~60°F
GEOLOGIST:	S. Roberts	DRLG FLUID	None	WEATHER:	Sunny, light breeze, low humidity
COMMENTS:					

Elev. (ft.)	Depth (ft.)	Profile	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1		SP	0-5.8': SAND, some gravel, fn to med, gravel up to 1", wet, lt. brown or buff, loose					~~Field = 20~~ Fill
	5								Field = 2000
			CL	5.8-7': CLAY ~~some~~ some silt, olive yellow mottled w/ grey, sl moist	1	5-7	G		Hdsp = 1800 ppm Didn't keep sample
				(2.5Y 6/6)					
	10			9.5-11.5': CL, olive yellow mottled w/ grey, dry to sl. moist, stiff, trace silt, fn. thin? cracks. black mottling (roots?)	1	9.5-11.5	G		Hdsp = >5000 ppm Didn't keep sample
	15								
				18-20': SAA	1	KE 84 MPB 18.5	C	18-20	~~Hdsp =~~
	20								
				22-24' SAA. very hard					~~Hdsp =~~
	25			TD = 25' BGS					
	30								

sl - slight
tr - trace
sm - some
& - and
@ - at
w - with

v - very
lt - light
dk - dark
bf - buff
brn - brown
blk - black

f - fine
m - medium
c - coarse
BH - Bore Hole
SAA - Same As Above

SAMPLE TYPE
D - DRIVE
C - CORE
G - GRAB

C Core recovery
Core lost

Water level drilled

GEOLOGIC BORING LOG

BORING NO.	MPC	CONTRACTOR:	JEDI	DATE SPUD:	01/08/94 1600
CLIENT:	AFCEE / Kelly AFB	RIG TYPE:	Mobile B-63	DATE CMPL:	01/08/94
JOB NO.:	722408.19040	DRLG METHOD:	HSA	ELEVATION:	
LOCATION:	2093 Kelly AFB	BORING DIA.:	8"	TEMP.:	~55°F
GEOLOGIST:	S Roberts	DRLG FLUID	None	WEATHER:	Partly cloudy, light breeze

COMMENTS:

Elev. (ft.)	Depth (ft.)	Pro-file	US CS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1		SP	0-5': SAND, some gravel, lt. brown					Fill.
									FID not working
									No Sample collected
	5								
			CL	5-7': CL, some silt, lt olive yellow mottled w/ green-gray (no Munsell ref.), microcracks in clay, sl. plastic, chalk lens @ 7', stiff					
	10								
				10-12': SAA, v. hard, chalk lens @ 11.2', ↑ silt & fn sand from 11.2 to 12'					
	15								
				SAA, some silt (increasing), chalk lens @ 16.3'.					
	20								
				SAA: yellow (2.5Y 7/6), CL & silt, dry, some fn sand, no plastic					
	25								
				TD = 25' BGS					
	30								

sl – slight	v – very	f – fine	**SAMPLE TYPE**
tr – trace	lt – light	m – medium	D – DRIVE C Core recovery
sm – some	dk – dark	c – coarse	C – CORE
& – and	bf – buff	BH – Bore Hole	G – GRAB Core lost
@ – at	brn – brown	SAA – Same As Above	
w – with	blk – black		Water level drilled

GEOLOGIC BORING LOG

BORING NO.:	~~K~~ Vent Well 1 (VW-)	CONTRACTOR:	JEDI	DATE SPUD:	01/06/94 0905
CLIENT:	AFCEE / Kelly AFB	RIG TYPE:	Mobile B-61	DATE CMPL:	01/06/94 1105 hrs
JOB NO.:	722408.19.0040	DRLG METHOD:	Hollow stem auger	ELEVATION:	
LOCATION:	Kelly AFB D-10	BORING DIA.:	~~7 1/4~~ 10 5/8"	TEMP.:	~55°F
GEOLOGIST:	J. Roberts	DRLG FLUID	None	WEATHER:	Clear, sunny, fairly dry

COMMENTS: Finished drill 1105 on 01/06/94 to 17' BGS

Elev. (ft.)	Depth (ft.)	Profile	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1								
			CL	Gravelly CLAY - brown (7.5YR 5/6) sl. moist	0			2-3'	
				Black & red clay ~~2.2~~ 3" (2.2-2.5'), [illegible] (1")					
	5			SAA (gravel [illegible] to 1.5') ~~black~~ [illegible] 7.5YR N3	1	4-5	G	4-5'	~~Hsp~~ 0 ~~Bkg 14 ppm~~, Bkg = 0.5 ppm
				70% clay 4.5 to 5', [illegible] gravel, sl. moist				5.5-7	Hsp = 0, bkg = 2 ppm
				SAA - 7.5YR 3/3, 6.3-6.4 gravel bed; SAA - Grav. Clay silt	1	5.5-7	G		
				SAA - 10YR 5/3 (8-8.1'), 10YR 3/1 8.5-9 CLAY					Hsp = 0, bkg = 2 ppm
				w/ gravel (1/16"), some rusty-red clay stringers (organics)	1	7.8-9	G	7.8-9	
	10			CLAY w/ gravel (5YR 2/2), gravel (1/16")					Hsp = 0, only sample kept.
					1	10-11	C	9-11	
				SAA - (5YR 3/1) 11-12' (2.5Y 4/2) 12-13', gravel					Hsp = 0, bkg = 0 ppm
				layer 12-12.1', mottled clay 12.5-13', moist, occ. roots	1	12-13	G		
				CL w/ gr. (7.5YR 7/1) 13' (2.5Y 6/2) 13.4-14' mottled,	1	13-14	G	13-14	Hsp = 60 ppm, bkg = 30 ppm
	15			~~SAA~~ CL w/ sl. gr. (10YR 7/2) to 15.5', 15.5-17 (2.5Y 6/4),				15-17	Bkg = 3 ppm
				clay w/ gravel, ∇ @ 15.5' (about)					
				TD = 17.3' BGS					
	20								
	25								
	30								

sl – slight	v – very	f – fine	**SAMPLE TYPE**
tr – trace	lt – light	m – medium	D – DRIVE; C Core recovery
sm – some	dk – dark	c – coarse	C – CORE
& – and	bf – buff	BH – Bore Hole	G – GRAB; Core lost
@ – at	brn – brown	SAA – Same As Above	
w – with	blk – black		Water level drilled

GEOLOGIC BORING LOG

BORING NO.	MPA	CONTRACTOR:	JEDI	DATE SPUD:	01/06/94 1345
CLIENT:	AFCEE / Kelly AFB	RIG TYPE:	Mobile B-63	DATE CMPL:	01/06/94 1435
JOB NO.:	722408.19.040	DRLG METHOD:	HSA	ELEVATION:	
LOCATION:	D-10 Kelly AFB	BORING DIA.:	8"	TEMP.:	~70°F
GEOLOGIST:	S. Roberts	DRLG FLUID	None	WEATHER:	Partly cloudy, dry

COMMENTS: Emplaced MP's after drill termination

Elev. (ft.)	Depth (ft.)	Profile	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1		GP	Gravel fill					
	5		CL	CL w/ gravel - (7.5YR 3/2) dark br, limst gravel occ. red (oxide) stringers, sl. moist, gravel = 1/16 - 1", NP, angular gravel	1	5.5-6.5	G	5.5-6.5'	HSP < 5, bag hdsp = 0
	10			SAA	1	9.5-10	G	9.5-10.5	HSP = 0, bag hdsp = 0
				SAA				9.5-11	Bag hdsp = 2 ppm
	15			GRAV. CL - blk (7.5YR N2/), sl. moist, gravel 1/16 - 3" angular limst & chert, 12.5-13' green sand (non-continuous) med to crs, found w/ blk clay	1	12-13	D		Bag hdsp = 5 ppm. Bag sample kept.
				TD = 14' BGS					
	20								
	25								
	30								

sl - slight	v - very	f - fine	**SAMPLE TYPE**
tr - trace	lt - light	m - medium	D - DRIVE
sm - some	dk - dark	c - coarse	C - CORE
& - and	bf - buff	BH - Bore Hole	G - GRAB
@ - at	brn - brown	SAA - Same As Above	
w - with	blk - black		

C Core recovery

Core lost

Water level drilled

GEOLOGIC BORING LOG

BORING NO.	MPB	CONTRACTOR:	JEDI	DATE SPUD:	01/06/94 1540
CLIENT:	AFCEE / Kelly AFB	RIG TYPE:	Mobile B63	DATE CMPL:	01/06/94 1620
JOB NO.:	722408.19.040	DRLG METHOD:	HSA	ELEVATION:	
LOCATION:	D10 Kelly AFB	BORING DIA.:	8"	TEMP.:	~70°
GEOLOGIST:	S. Roberts	DRLG FLUID	None	WEATHER:	Partly cloudy, dry

COMMENTS:

Elev. (ft.)	Depth (ft.)	Profile	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1								-
				~~Fill - cotton trace in top 1 core~~					
				5.5-6'				4.5-6.5	Hisp = 0, field screen = 0
	5		SP	~~5-5.5'~~: GRAV SAND (dk grey-br) 10YR 4/2, med to	1	5.5-6.5	G		
				crs, gravel = 1/16 - 0.5" angular, dry, 5.5-6-6.5' -					
			CL	CL w/gravel - same color, dry to sl. moist, N plastic,					
				red oxide (organics) in stringers					
				SAA w/ sand - v. dk grey (10YR 3/1), sl. moist, stiff, gravel					field screen = 3 ppm,
	10			is 1/16 to 1.25", gravel/clay 9-9.2", 5% sand	1	9-10	~~D~~ C	8-10	Hisp = 2 ppm
									Only sample kept for analysis
				CL w/sand & gravel - olive grey (5Y 5/2) sl. moist				12-14	Field screen = 0, Hisp = 0
				crs sand, 1/16-1" gravel, color grades to light grey (5Y 7/2),	1	13-14	G		
	15			green sand (occ.) and 1-2 gravels					
				TD = 14' BGS					
	20								
	25								
	30								

sl - slight
tr - trace
sm - some
& - and
@ - at
w - with

v - very
lt - light
dk - dark
bf - buff
brn - brown
blk - black

f - fine
m - medium
c - coarse
BH - Bore Hole
SAA - Same As Above

SAMPLE TYPE
D - DRIVE
C - CORE
G - GRAB

C Core recovery

Core lost

Water level drilled

GEOLOGIC BORING LOG

BORING NO.	MPC	CONTRACTOR:	JEDI	DATE SPUD:	01/07/94 1455
CLIENT:	AFCEE / Kelly AFB	RIG TYPE:	~~HSA~~ Mobile B-63	DATE CMPL:	01/07/94 1545
JOB NO.:	722408.19040	DRLG METHOD:	HSA	ELEVATION:	
LOCATION:	D-10 Kelly AFB	BORING DIA.:	8"	TEMP.:	~45°F
GEOLOGIST:	S. Roberts	DRLG FLUID	None	WEATHER:	Sunny, high cirrus clouds, windy

COMMENTS: Emplaced 3 MP monitoring probes @ 3 depths after drilling termination.

Elev. (ft.)	Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1		CL	0-0.5': asphalt + base. 0.5- ': CL, some gravel, yellow (10YR 7/6) & blk & dk brown, angular gravel up to 1", some silt & sand, cs to fn					
	5			4.5-6.5'					
				5-7': CL, little sand, trace gravel, black (10YR 2/1) chert gravel up to 1/4", cs sand					0.5" recovery
	10			9.5-11.5': SAA, some chert gravel (1/4 to 3/4")					SAA
				12-13': CL and gravel, lt gray (10YR 7/2) to 3/4", some cs. sand sl. moist, v. dk gray (10YR 3/1) @ 12.5', 3" chert cobble, some bedding in clay, sl plastic	1	12-13	G		Bkgrnd = 2 ppm Resp = 4 ppm Did not keep sample.
	15			TD = 14' BGS					
	20								
	25								
	30								

sl – slight	v – very	f – fine	**SAMPLE TYPE**
tr – trace	lt – light	m – medium	D – DRIVE C Core recovery
sm – some	dk – dark	c – coarse	C – CORE
& – and	bf – buff	BH – Bore Hole	G – GRAB Core lost
@ – at	brn – brown	SAA – Same As Above	
w – with	blk – black		Water level drilled

Appendix B

Chain-of-Custody Forms

AIR TOXICS LTD.
AN ENVIRONMENTAL ANALYTICAL LABORATORY

180 BLUE RAVINE ROAD, SUITE B
FOLSOM, CA 95630
(916) 985-1000 • FAX (916) 985-1020

CHAIN OF CUSTODY RECORD

Page 1 of 1

PROJECT # DE268.19.04 DE268.19.06 PO # 722408.08090 COLLECTED BY (Signature) Brian Vanderglas Jason Roberts

REMARKS Kelly AFB - 12 month test at site FC-2 (KE-2)
Initial pilot test at sites D-10 (KE3) and 82093 (KE-4)
KE4 samples probably diluted by atmospheric interferences.

	FIELD SAMPLE I.D.#	SAMPLING MEDIA (Tenax, Canister etc.)	DATE/TIME	ANALYSIS	VAC./PRESSURE	LAB I.D. #
01A	KE2 MPA13.5	AT 9392	21 Jan 94/1400	TO-3/TVH & BTEX	0"Hg	
02A	KE2 VW	AT 9372	21 Jan 94/1640	TO-3/TVH & BTEX	0"Hg	
03A	KE2 MPC13.5	AT 9376	21 Jan 94/1404	TO-3/TVH & BTEX	0"Hg	
04A	KE3 MPC 13.5	AT 9390	17 Jan 94/1418	TO-3/TVH & BTEX	0"Hg	
05A	KE 3 MPA 13.5	AT 9304	17 Jan 94/1414	TO-3/TVH & BTEX	1"Hg	
06A	KE 3 VW	AT 9386	17 Jan 94/1410	TO-3/TVH & BTEX	1"Hg	
07A	KE4 MPA 12	11442	12 Jan 94/1200	TO-3/TVH & BTEX	6"Hg	
08A	KE4 MPB 18	AT 9375	12 Jan 94/1205	TO-3/TVH & BTEX	1"Hg	
09A	KE4 VW1	AT 9321	12 Jan 94/1154	TO-3/TVH & BTE	0"Hg	

RELINQUISHED BY: DATE/TIME	RECEIVED BY: DATE/TIME	RELINQUISHED BY: DATE/TIME	RECEIVED BY: DATE/TIME
Jason Roberts 1/24/94 1945	Theresa Schmidt ATL 1/25/94 10:40		

LAB USE ONLY

SHIPPER NAME	AIR BILL #	OPENED BY: DATE/TIME	TEMP(°C)	CONDITION

REMARKS Custody seals not present 1/25/94 [illegible]

CHAIN OF CUSTODY RECORD

ENGINEERING-SCIENCE, INC.
1700 BROADWAY, SUITE 900
DENVER, COLORADO 80290
303-831-8100

AFCEE BIOVENTING PILOT TESTS

Base: Kelly AFB

Site: D10 / KE3

ES Job No.
DE268. 19 . 04 .08

Sampler(s): (Signature) [signature] [signature]

Ship To:

PACE INCORPORATED
5702 Bolsa Ave.
Huntington Beach, CA 92649

Attn: Melony Concepcion
(714) 892-2565

					Preservative: NONE	NONE	NONE	NONE	HOLD	AT 4C	NONE	NONE	NONE			
Date	Time	Sample Description	Lab I.D.	No. of Contrs.	SW 9045 (PH)	A 403 (ALKA)	SW 7380 (IRON)	SW 846 (MOIST)	SW 8020 (BTEX)	E 418.1 (TRPH)	E 351.2 (TKN)	E 365.3 (PHOS)	UCM (CLASS)	Sample Type	Matrix	Remarks
1/6/94	1000	KE3 VW1: 10			X	X	X	X	X	X	X	X	X	G C	SOIL	3 bottles 8 oz.
1/6/94	1420	KE3 MPA: 12			X	X	X	X	X	X	X	X	X	G C	SOIL	3 bottles 8 oz.
1/6/94	1605	KE3 MPB: 9			X	X	X	X	X	X	X	X	X	G C	SOIL	3 bottles 8 oz.
														G C	SOIL	
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Relinquished by: (Signature)	Date / Time	Recieved for Laboratory by: (Signature)	Date / Time
[signature]	1/10/94 1830		
Relinquished by: (Signature)	Date / Time	Recieved for Laboratory by: (Signature)	Date / Time

Remarks:

G - Grab Sample, C - Composite Sample

Distribution: Original Accompanies Shipment. Copies to: Coordinator Field Files

Federal Express Number:

Airbill Number: 9747130746

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CCRSOIL

Page 1 of 1

CHAIN OF CUSTODY RECORD

ENGINEERING-SCIENCE, INC.
1700 BROADWAY, SUITE 900
DENVER, COLORADO 80290
303-831-8100

ES Job No.
DE268. 19 04.08

AFCEE BIOVENTING PILOT TESTS

Base: Kelly AFB

Site: 82093 / KE4

Sampler(s): (Signature) [illegible] [illegible]

Ship To:
PACE INCORPORATED
5702 Bolsa Ave.
Huntington Beach, CA 92649

Attn: Melony Concepcion
(714) 892-2565

					Preservative: NONE	NONE	NONE	NONE	HOLD AT 4C	HOLD AT 4C	NONE	NONE	NONE			
Date	Time	Sample Description	Lab I.D.	No. of Contrs.	SW 9045 (PH)	A 403 (ALKA)	SW 7380 (IRON)	SW 846 (MOIST)	SW 8020 (BTEX)	E 418.1 (TRPH)	E 351.2 (TKN)	E 365.3 (PHOS)	UCM (CLASS)	Sample Type	Matrix	Remarks
1/7/94	1030	KE4 VW1 : 15			X	X	X	X	X	X	X	X	X	G C	SOIL	3 bottles - 8 oz.
1/8/94	0800	KE4 MPA : 12			X	X	X	X	X	X	X	X	X	G C	SOIL	3 brass sleeves - 4"
1/8/94	1445	KE4 MPB : 18			X	X	X	X	X	X	X	X	X	G C	SOIL	3 brass sleeves - 4"
														G C	SOIL	
														G C	SOIL	
														G C	SOIL	
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														G C	SOIL	

(Analysis Required)

Relinquished by: (Signature)	Date / Time	Recieved for Laboratory by: (Signature)	Date / Time
[illegible]	1/10/94 1830		
Relinquished by: (Signature)	Date / Time	Recieved for Laboratory by: (Signature)	Date / Time

Remarks:

G - Grab Sample, C - Composite Sample

Distribution: Original Accompanies Shipment. Copies to: Coordinator Field Files
Federal Express Number:
Airbill Number: 9747130746

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Appendix C

Calculation Sheets

KELLY AFB – Site B2093; 18 and 24 feet borings
Steady–state Equation – Air Injection

Enter data
Calculated data

$$k = \frac{Q\,\mu\,\ln(Rw/Ri)}{H\,\pi\,Patm\,[\,1 - (Pw/Patm)^2\,]}$$

Where:

Q = Volumetric flow rate of vent well

20.0	scfm x (30.48 cm/ft)^3 x (1 min/60 s) =	9.44E+03	cm^3/s

μ = Viscosity of Air @ 18° C = 1.80E−04 g/cm s

Patm = Ambient pressure @ 1300 feet of elevation

389	inches H2O x (3.61E−2 psia/in. H2O) =	14.043	psia
14.043	psia x (6.89476E4 g/cm s^2)/psia =	9.68E+05	g/cm s^2

Rw = Radius of Vent Well

2	inches x 2.54 cm/in =	5.08	cm

H = Depth of Screen (length of screened interval)

19.6	feet x 30.48 cm/ft =	597	cm

Ri = Maximum Radius of Venting Influence

15	feet x 30.48 cm/ft =	457	cm

Pw = Absolute Pressure at Vent Well

277	inches H2O x (3.61E−2 psia/in. H2O) =	10.000	psia
10.000	psia + 14.043 psia =	24.043	psia
24.043	psia x (6.89476E4 g/cm s^2)/psia =	1.66E+06	g/cm s^2

	k =	2.178E−09	cm^2
2.200E−09	cm^2 x (1 m/100 cm)^2 =	2.000E−13	m^2
2.000E−13	m^2 x 1 darcy/(9.870E−13 m^2) =	0.2	darcys

KELLY AFB – Site B2093; 12 feet boring
Steady–state Equation – Air Injection

Enter data
Calculated data

$$k = \frac{Q \mu \ln(Rw / Ri)}{H \pi Patm [1 - (Pw / Patm)^2]}$$

Where:

Q = Volumetric flow rate of vent well

20.0	scfm x $(30.48\ cm/ft)^3$ x (1 min/60 s) =	9.44E+03	cm^3/s

μ = Viscosity of Air @ 18° C = 1.80E–04 g/cm s

Patm = Ambient pressure @ 1300 feet of elevation

389	inches H2O x (3.61E–2 psia/in. H2O) =	14.043	psia
14.043	psia x (6.89476E4 $g/cm\ s^2$)/psia =	9.68E+05	$g/cm\ s^2$

Rw = Radius of Vent Well

2	inches x 2.54 cm/in =	5.08	cm

H = Depth of Screen (length of screened interval)

19.6	feet x 30.48 cm/ft =	597	cm

Ri = Maximum Radius of Venting Influence

9	feet x 30.48 cm/ft =	274	cm

Pw = Absolute Pressure at Vent Well

277	inches H2O x (3.61E–2 psia/in. H2O) =	10.000	psia
10.000	psia + 14.043 psia =	24.043	psia
24.043	psia x (6.89476E4 $g/cm\ s^2$)/psia =	1.66E+06	$g/cm\ s^2$
	k =	1.931E–09	cm^2
1.900E–09	cm^2 x $(1\ m/100\ cm)^2$ =	2.000E–13	m^2
2.000E–13	m^2 x 1 darcy/(9.870E–13 m^2) =	0.2	darcys

KELLY AFB – Site D–10 5.5' Depth
Steady–state Equation – Air Injection

Enter data

Calculated data

$$k = \frac{Q \mu \ln(Rw/Ri)}{H \pi Patm [1 - (Pw/Patm)^2]}$$

Where: From Blower Curve

Q = Volumetric flow rate of vent well

34.0	scfm x (30.48 cm/ft)^3 x (1 min/60 s) =	1.60E+04	cm^3/s
	μ = Viscosity of Air @ 18° C =	1.80E–04	g/cm s

Patm = Ambient pressure @ 1250 feet of elevation

390	inches H2O x (3.61E–2 psia/in. H2O) =	14.079	psia
14.079	psia x (6.89476E4 g/cm s^2)/psia =	9.71E+05	g/cm s^2

Rw = Radius of Vent Well

2	inches x 2.54 cm/in =	5.08	cm

H = Depth of Screen (length of screened interval)

9.6	feet x 30.48 cm/ft =	293	cm

Ri = Maximum Radius of Venting Influence

40	feet x 30.48 cm/ft =	1219	cm

Pw = Absolute Pressure at Vent Well

48	inches H2O x (3.61E–2 psia/in. H2O) =	1.733	psia
1.733	psia + 14.079 psia =	15.812	psia
15.812	psia x (6.89476E4 g/cm s^2)/psia =	1.09E+06	g/cm s^2
	k =	6.789E–08	cm^2
6.790E–08	cm^2 x (1 m/100 cm)^2 =	6.800E–12	m^2
6.800E–12	m^2 x 1 darcy/(9.870E–13 m^2) =	6.89	darcys

KELLY AFB – Site D–10 9.5' Depth
Steady–state Equation – Air Injection

Enter data

Calculated data

$$k = \frac{Q \mu \ln(\cdot Rw / Ri)}{H \pi \, Patm [1 - (Pw / Patm)^2]}$$

Where: From Blower Curve

Q = Volumetric flow rate of vent well

34.0	scfm x (30.48 cm/ft)^3 x (1 min/60 s) =	1.60E+04	cm^3/s

μ = Viscosity of Air @ 18° C = 1.80E–04 g/cm s

Patm = Ambient pressure @ 1250 feet of elevation

390	inches H2O x (3.61E–2 psia/in. H2O) =	14.079	psia
14.079	psia x (6.89476E4 g/cm s²)/psia =	9.71E+05	g/cm s²

Rw = Radius of Vent Well

2	inches x 2.54 cm/in =	5.08	cm

H = Depth of Screen (length of screened interval)

9.6	feet x 30.48 cm/ft =	293	cm

Ri = Maximum Radius of Venting Influence

45	feet x 30.48 cm/ft =	1372	cm

Pw = Absolute Pressure at Vent Well

48	inches H2O x (3.61E–2 psia/in. H2O) =	1.733	psia
1.733	psia + 14.079 psia =	15.812	psia
15.812	psia x (6.89476E4 g/cm s²)/psia =	1.09E+06	g/cm s²

k = 6.935E–08 cm²

6.940E–08	cm² x (1 m/100 cm)² =	6.900E–12	m²
6.900E–12	m² x 1 darcy/(9.870E–13 m²) =	6.99	darcys

KELLY AFB – Site D–10 13.5' Depth
Steady–state Equation – Air Injection

Enter data

Calculated data

$$k = \frac{Q \mu \ln (Rw / Ri)}{H \pi \, Patm [1 - (Pw / Patm)^2]}$$

Where: From Blower Curve

Q = Volumetric flow rate of vent well

34.0 scfm x (30.48 cm/ft)^3 x (1 min/60 s) = 1.60E+04 cm^3/s

μ = Viscosity of Air @ 18° C = 1.80E–04 g/cm s

Patm = Ambient pressure @ 1250 feet of elevation

390 inches H2O x (3.61E–2 psia/in. H2O) = 14.079 psia

14.079 psia x (6.89476E4 g/cm s^2)/psia = 9.71E+05 g/cm s^2

Rw = Radius of Vent Well

2 inches x 2.54 cm/in = 5.08 cm

H = Depth of Screen (length of screened interval)

9.6 feet x 30.48 cm/ft = 293 cm

Ri = Maximum Radius of Venting Influence

50 feet x 30.48 cm/ft = 1524 cm

Pw = Absolute Pressure at Vent Well

48 inches H2O x (3.61E–2 psia/in. H2O) = 1.733 psia

1.733 psia + 14.079 psia = 15.812 psia

15.812 psia x (6.89476E4 g/cm s^2)/psia = 1.09E+06 g/cm s^2

k = 7.065E–08 cm^2

7.070E–08 cm^2 x (1 m/100 cm)^2 = 7.100E–12 m^2

7.100E–12 m^2 x 1 darcy/(9.870E–13 m^2) = 7.19 darcys

Respiration Test
Site D-10
Kelly AFB, Texas

Monitoring Point	Date	Days Elapsed (frac. days)	Time	Hrs elapsed (fractional days)	Days Elapsed	Elapsed Time (min. x 1000)	O2%	CO2%	Total Hydro-carbon	Helium	Comments	Trend of O2/ Time	New x-values	k
VW	01/18/94	0.00	10:15	0.01	0.01	0.01	20.25	0.25	<0	1.8	Hydrocarbon meter reads negative.	19.47369625	0	0.014267
VW	01/18/94	0.00	10:43	0.03	0.03	0.04	19.00	0.40	<0	2.5	Hydrocarbon meter reads negative.	9.201640045	0.72	
VW	01/18/94	0.00	11:30	0.06	0.06	0.09	18.00	0.40	<0	2.4	Hydrocarbon meter reads negative.			
VW	01/18/94	0.00	13:15	0.14	0.14	0.20	16.50	0.55	<0	2.2	Hydrocarbon meter reads negative.			
VW	01/18/94	0.00	15:12	0.22	0.22	0.31	14.10	0.60	<0	2.7	Hydrocarbon meter reads negative.			
VW	01/18/94	0.00	17:02	0.29	0.29	0.42	12.80	0.75	<0	2.5	Hydrocarbon meter reads negative.			
VW	01/18/94	0.00	22:02	0.50	0.50	0.72	10.00	0.75	<0	2.9	Hydrocarbon meter reads negative.			
VW	01/19/94	1.00	09:45	-0.01	0.99	1.43	5.00	1.10	2	2.8				
VW	01/19/94	1.00	17:18	0.30	1.30	1.88	3.00	1.50	0	2.7	5 minute purge before each sampling.			
VW	01/20/94	2.00	08:25	-0.07	1.93	2.79	1.50	2.10	0	2.8				
VW	01/20/94	2.00	16:34	0.27	2.27	3.27	0.90	2.75	5	2.6				
VW	01/21/94	3.00	11:14	0.05	3.05	4.39	0.25	2.75	90	1.9	Top open-plumb blower-1700 hrs 20 Jan 94			
MPA-13.5	01/18/94	0.00	10:19	0.01	0.01	0.02	19.25	0.25	<0	2.8	Hydrocarbon meter reads negative.	18.81792626	0	0.049098
MPA-13.5	01/18/94	0.00	10:46	0.03	0.03	0.05	16.90	0.40	16	2.2		-2.29411896	0.43	
MPA-13.5	01/18/94	0.00	11:37	0.07	0.07	0.10	14.25	0.40	97	2.0				
MPA-13.5	01/18/94	0.00	13:18	0.14	0.14	0.20	6.50	0.60	320	3.0				
MPA-13.5	01/18/94	0.00	15:14	0.22	0.22	0.31	2.00	0.60	430	2.6				
MPA-13.5	01/18/94	0.00	17:06	0.30	0.30	0.43	0.00	0.75	430	3.6				
MPB-9.5	01/18/94	0.00	10:25	0.02	0.02	0.02	20.25	0.10	<0	2.3	Hydrocarbon meter reads negative.	20.35938009	0	0.003454
MPB-9.5	01/18/94	0.00	10:52	0.04	0.04	0.05	20.10	0.10	<0	2.4	Hydrocarbon meter reads negative.	13.86600211	1.88	
MPB-9.5	01/18/94	0.00	11:42	0.07	0.07	0.10	20.10	0.10	<0	2.9	Hydrocarbon meter reads negative.			
MPB-9.5	01/18/94	0.00	13:24	0.14	0.14	0.20	20.00	0.20	<0	2.7	Hydrocarbon meter reads negative.			
MPB-9.5	01/18/94	0.00	15:20	0.22	0.22	0.32	19.10	0.20	<0	2.5	Hydrocarbon meter reads negative.			
MPB-9.5	01/18/94	0.00	17:11	0.30	0.30	0.43	18.90	0.30	<0	2.6	Hydrocarbon meter reads negative.			
MPB-9.5	01/18/94	0.00	22:08	0.51	0.51	0.73	17.50	0.30	<0	2.2	Hydrocarbon meter reads negative.			
MPB-9.5	01/19/94	1.00	09:53	0.00	1.00	1.43	15.50	0.70	<0	1.8	Hydrocarbon meter reads negative.			
MPB-9.5	01/19/94	1.00	17:23	0.31	1.31	1.88	13.90	0.80	<0	1.3	Hydrocarbon meter reads negative.			
MPB-9.5	01/20/94	2.00	08:30	-0.06	1.94	2.79	12.75	1.25	6	1.2				
MPB-9.5	01/20/94	2.00	16:40	0.28	2.28	3.28	12.00	1.75	6	1.2	1 minute purge time before each sampling.			
MPB-9.5	01/21/94	3.00	11:20	0.06	3.06	4.40	11.75	2.10	26	1.0				
MPB-13.5	01/18/94	0.00	10:22	0.02	0.02	0.02	20.00	0.10	<0	2.3	1 minute purge time before each sampling.	20.04703888	0	0.009615
MPB-13.5	01/18/94	0.00	10:48	0.03	0.03	0.05	19.80	0.10	<0	2.4	Hydrocarbon meter reads negative.	13.02840077	0.73	
MPB-13.5	01/18/94	0.00	11:40	0.07	0.07	0.10	19.20	0.10	<0	2.5	Hydrocarbon meter reads negative.			
MPB-13.5	01/18/94	0.00	13:21	0.14	0.14	0.20	18.10	0.25	<0	2.7	Hydrocarbon meter reads negative.			
MPB-13.5	01/18/94	0.00	15:18	0.22	0.22	0.32	16.50	0.25	<0	2.5	Hydrocarbon meter reads negative.			
MPB-13.5	01/18/94	0.00	17:09	0.30	0.30	0.43	15.50	0.30	<0	2.5	Hydrocarbon meter reads negative.			
MPB-13.5	01/18/94	0.00	22:06	0.50	0.50	0.73	13.50	0.25	<0	2.8	Hydrocarbon meter reads negative.			
MPB-13.5	01/19/94	1.00	09:50	-0.01	0.99	1.43	9.80	0.50	<0	2.7	Hydrocarbon meter reads negative.			
MPB-13.5	01/19/94	1.00	17:21	0.31	1.31	1.88	8.50	0.50	<0	3.3	Hydrocarbon meter reads negative.			
MPB-13.5	01/20/94	2.00	08:28	-0.06	1.94	2.79	5.50	0.60	<0	2.7	Hydrocarbon meter reads negative.			
MPB-13.5	01/20/94	2.00	16:37	0.28	2.28	3.28	4.50	0.60	<0	3.3	Hydrocarbon meter reads negative.			
MPB-13.5	01/21/94	3.00	11:18	0.05	3.05	4.40	3.00	0.60	<0	2.5	Hydrocarbon meter reads negative.			
MPC-13.5	01/18/94	0.00	10:30	0.02	0.02	0.03	19.80	0.10	<0	2.1	Hydrocarbon meter reads negative.	18.95731453	0	0.017774
MPC-13.5	01/18/94	0.00	10:55	0.04	0.04	0.06	18.50	0.25	<0	1.9	Hydrocarbon meter reads negative.	5.982087509	0.73	

MPC-13.5	01/18/94	0.00	11:44	0.07	0.07	0.10	17.50	0.25	<0	1.7	Hydrocarbon meter reads negative.				
MPC-13.5	01/18/94	0.00	13:26	0.14	0.14	0.21	14.80	0.25	<0	1.7	Hydrocarbon meter reads negative.				
MPC-13.5	01/18/94	0.00	15:22	0.22	0.22	0.32	11.50	0.25	17	1.7					
MPC-13.5	01/18/94	0.00	17:14	0.30	0.30	0.43	9.25	0.50	83	1.7	1 minute purge time before each sampling.				
MPC-13.5	01/18/94	0.00	22:11	0.51	0.51	0.73	7.90	0.50	68	1.7					
MPC-13.5	01/19/94	1.00	09:55	0.00	1.00	1.44	4.80	0.70	14	1.7					
MPC-13.5	01/19/94	1.00	17:26	0.31	1.31	1.89	1.75	0.75	<0	1.7	Hydrocarbon meter reads negative.				
MPC-13.5	01/20/94	2.00	08:33	-0.06	1.94	2.79	2.10	0.80	<0	1.7	Hydrocarbon meter reads negative.				
MPC-13.5	01/20/94	2.00	16:42	0.28	2.28	3.28	1.10	1.00	<0	1.7	Hydrocarbon meter reads negative.				
MPC-13.5	01/21/94	3.00	11:23	0.06	3.06	4.40	0.50	1.10	<0	1.7	Hydrocarbon meter reads negative.				

KELLY AFB - Site D-10
Biodegradation Rate Calculations

enter data	calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPC-13.5

K_o = max. observed rate 0.01777 %/min.
w = moisture content 19.9 %

Assume: Soil properties for soft glacial clay Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	n =	0.55
Unit weight (dry):	d =ᵍ	1.22
Void ratio:	$e = n/(1-n)$ =	1.22
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.

Solving for 1 liter of soil

a) $V_v = n * 1$ L
$=V_v$ 0.55 liters V_v = void volume

b) $S_r = Gw/e$
$=S_r$ 0.43 S_r = degree of saturation

c) $V_w = S_r \times V_v$
$=V_w$ 0.24 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$
$=V_a$ 0.31 liters V_a = volume of air

e) Bulk density = ᵍd + (V_w x ᵍw) = 1.5 kg/l soil

f) A = V_a/Bulk density = 0.207 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 7400 mg TPH/year

afbio4/1kellykb/lcw/3.29.94

KELLY AFB – Site D–10
Biodegradation Rate Calculations

enter data	calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPB–13.5 K_o = max. observed rate 0.00962 %/min.
w = moisture content 19.9 %

Assume: Soil properties for soft glacial clay Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	n =	0.55
Unit weight (dry):	γd =	1.22
Void ratio:	$e = n/(1-n)$ =	1.22
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
V_v = 0.55 liters V_v = void volume

b) $S_r = Gw/e$
S_r = 0.43 S_r = degree of saturation

c) $V_w = S_r \times V_v$
V_w = 0.24 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$
V_a = 0.31 liters V_a = volume of air

e) Bulk density = $\gamma d + (V_w \times \gamma w)$ = 1.5 kg/l soil

f) A = V_a/Bulk density = 0.207 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 4010 mg TPH/year

afbio4/2kellykb/lcw/3.21.94

KELLY AFB – Site D–10
Biodegradation Rate Calculations

enter data	calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPA–13.5

K_o = max. observed rate 0.04910 %/min.

w = moisture content 19.9 %

Assume: Soil properties for soft glacial clay Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	$n =$	0.55
Unit weight (dry):	$\gamma_d =$	1.22
Void ratio:	$e = n/(1-n) =$	1.22
Specific gravity:	$G =$	2.65

Calculate A = Air filled volume (V_a)/unit wt.

Solving for 1 liter of soil

a) $V_v = n * 1$ L

$V_v =$ 0.55 liters V_v = void volume

b) $S_r = Gw/e$

$S_r =$ 0.43 S_r = degree of saturation

c) $V_w = S_r \times V_v$

$V_w =$ 0.24 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$

$V_a =$ 0.31 liters V_a = volume of air

e) Bulk density = $\gamma_d + (V_w \times \gamma_w)$ = 1.5 kg/l soil

f) A = V_a/Bulk density = 0.207 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 20450 mg TPH/year

KELLY AFB – Site D–10
Biodegradation Rate Calculations

enter data	calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: VW

K_o = max. observed rate	0.01427	%/min.
w = moisture content	23.4	%

Assume: Soil properties for soft glacial clay Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	$n =$	0.55
Unit weight (dry):	$\gamma d =$	1.22
Void ratio:	$e = n/(1-n) =$	1.22
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
$V_v =$ 0.55 liters V_v = void volume

b) $S_r = Gw/e$
$S_r =$ 0.51 S_r = degree of saturation

c) $V_w = S_r \times V_v$
$V_w =$ 0.28 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$
$V_a =$ 0.27 liters V_a = volume of air

e) Bulk density = $\gamma d + (V_w \times \gamma w)$ = 1.5 kg/l soil

f) $A = V_a$/Bulk density = 0.18 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 5170 mg TPH/year

KELLY AFB – Site D–10
Biodegradation Rate Calculations

enter data	calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

$K_o = O_2$ utilization rate (%/min.)

A = volume of air/kg soil

$D_o = O_2$ density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPB–9.5 K_o = max. observed rate 0.00345 %/min.
w = moisture content 24.1 %

Assume: Soil properties for soft glacial clay Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	n =	0.55
Unit weight (dry):	$^g d$ =	1.22
Void ratio:	$e = n/(1-n)$ =	1.22
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
V_v = 0.55 liters V_v = void volume

b) $S_r = Gw/e$
S_r = 0.52 S_r = degree of saturation

c) $V_w = S_r \times V_v$
V_w = 0.29 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$
V_a = 0.26 liters V_a = volume of air

e) Bulk density = $^g d + (V_w \times {^g w})$ = 1.5 kg/l soil

f) A = V_a/Bulk density = 0.173 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 1200 mg TPH/year

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